Government of **Western Australia**
Department of **Water**

River health assessment in the lower catchment of the Blackwood River

Assessments in the Chapman and Upper Chapman brooks, the McLeod, Rushy and Fisher creeks and the lower Blackwood River using the South West Index of River Condition

Securing Western Australia's water future

Water*Science*
technical series

Report no. WST 68
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Report to the South West Catchments Council

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Cover photograph: lower reach of McLeod Creek, February 2013 (T. Storer)

Disclaimer

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Summary

This study was developed collaboratively between the South West Catchments Council (SWCC) and Department of Water (DoW) to provide river health data to meet the following requirements:

- SWCC secured funding to undertake a program of on-ground works to address threats to the lower Blackwood high ecological value aquatic ecosystem (HEVAE). A core component of the SWCC works program was to establish a baseline ecosystem health dataset against which the effectiveness of the on-ground works could be evaluated.
- SWCC commissioned a river action plan (RAP) for the McLeod and Rushy creeks to guide natural resource management activities for protecting the ecological, social and cultural value of the creeks. Ecosystem health data were required to contribute to the assessment of the creeks' current condition.
- The Department of Water identified the need to collect ecosystem health data for the lower Blackwood River catchment, to inform water resource management decisions and contribute to the development of the Stage 2 water quality improvement plan (WQIP) for the Hardy Inlet (DoW in prep.).

These data requirements were met by applying the South West Index of River Condition (SWIRC), which provides a suite of protocols for collecting and analysing data. This includes a standardised scoring system for a series of indices and sub-indices, so that results can be compared between river systems across south-west Western Australia. The scoring protocols are based on a reference condition approach, and provide a measure of the departure of observed values from those typically expected under minimal disturbance conditions.

Overall the ecological health of the waterways was good, with most SWIRC theme scores for each system categorised as largely unmodified and slightly modified.

Thirteen native fish and crayfish species were found, 11 of which are endemic to south-west Western Australia. The community included one Threatened species, *Galaxiella munda*, (listed under the *Wildlife Conservation Act 1950,* DPAW 2013) and one Priority 1 species, *Geotria australis (*listed by DPAW 2013). There was a high richness of native fish and crayfish species compared with other sites in south-west Western Australia, in particular at two sites in McLeod Creek and one site in Upper Chapman Brook.

Evidence suggesting the presence of nursery and spawning areas was found at several sites in the tributaries, including evidence of recent spawning of *G. munda* in Fisher Creek. Given that *G. munda* is listed as a Threatened species, protecting the spawning habitat is important.

Potential permanent water refugia were identified in McLeod Creek and Upper Chapman Brook, and may also occur in Rushy Creek and Chapman Brook. Given the observed and predicted impacts of climate change in south-west Western Australia, the presence, duration and quality of permanent water refugia will become increasingly important to the protection of aquatic biodiversity.

Other key values identified include:

- a diverse macroinvertebrate community with two potentially new larval forms of caddisfly, several endemic or Gondwanic species and one species – *Westralunio carteri* – listed as Priority 4 by DPAW (2013)
- a high extent of fringing zone vegetation on half of the reaches
- water and sediment quality that was generally within guidelines.

Based on the results of the study, several potential threats to aquatic ecological health were identified. Dry conditions were observed at a number of sites in February 2013, and potential impacts of these conditions were noted in the assessment of aquatic biota. Given the lack of historical flow data for these river systems, it is not possible to determine whether the degree of drying is natural (i.e. if the systems are naturally ephemeral), or if the drying, and associated low species richness, reflects changing climate conditions. However, general drying climate trends across south-west Western Australia suggest that current patterns of drying are likely to extend both spatially and temporally.

Other potential threats related to the fringing vegetation and physical form of the systems. Further, exceedences of water quality guidelines for total nitrogen and diel (24-hour) dissolved oxygen may warrant further investigation.

In summary, a number of ecological values were identified in the study area, including high native species richness and endemism, and nursery and spawning areas for fish and crayfish. These values were found across the study area, including at sites where potential threats, such as reduced fringing vegetation and extensive erosion, were identified. Given that the aquatic biota index scores were in the top two condition bands for most sites, including those with lower scores for the fringing zone and physical form indices, this suggests that the aquatic biota community has sufficient resilience to withstand these pressures at present. However, this resilience may not continue in the future, thus consideration should be given to further investigation and management of these potential threats to aquatic ecosystem health.

As with any short-term monitoring program, the data analysis and SWIRC scores presented in this study represent a snapshot of the ecological health of the river systems at a given point in time; accordingly some values and threats may remain undetected. The results form a baseline for more detailed, targeted assessment (see Section 7, Knowledge gaps).

1 Introduction

This study was developed collaboratively between the South West Catchments Council (SWCC) and Department of Water to provide river health data to meet the following requirements:

- SWCC secured funding from the Caring for our Country (CFOC) investment program 2010–13 to undertake a program of on-ground works to address threats to the lower Blackwood high ecological value aquatic ecosystem (HEVAE)[1] (Appendix A). A core component of the SWCC works program was to establish a baseline ecosystem health dataset against which the effectiveness of the on-ground works could be evaluated.
- SWCC commissioned a river action plan for the McLeod and Rushy creeks to guide natural resource management activities to protect the ecological, social and cultural values of the creeks. Ecosystem health data were required to contribute to the assessment of the creeks' current condition.
- The Department of Water identified the need to collect ecosystem health data for the lower Blackwood River catchment, to inform water resource management decisions and to contribute to the development of the Stage 2 water quality improvement plan (WQIP) for the Hardy Inlet (DoW in prep.).

Several tributaries of the lower Blackwood River were assessed: the Chapman and Upper Chapman brooks, and the McLeod, Rushy and Fisher creeks.

This report presents the data gathered by the study and summarises the values and potential threats identified for each tributary. An overview of the data is presented in a series of brochures available from the SWCC: http://www.swnrmstrategy.org.au/wordpress/regional-report-cards/.

1.1 Study objectives

- To provide an assessment of river health that will serve as a baseline against which future change can be measured (for example in evaluation of restoration areas and assessing impacts of land management practices).
- To provide river health data to support the development of a river action plan for the McLeod and Rushy creeks.
- To provide river health data (and establish river health monitoring sites) to inform water resource management decisions and contribute to the Stage 2 WQIP for the Hardy Inlet.

[1] The lower Blackwood River and a number of its tributaries were identified as being a HEVAE in the CFOC business plan for 2009–10 (Commonwealth of Australia 2008) and subsequent plans, including the 2012–13 site investment guides (Commonwealth of Australia 2011).

2 Study area

2.1 Location

The study area is located in the Lower Blackwood surface water allocation area, in south-west Western Australia (Figure 1). The study focuses on McLeod and Rushy creeks and Chapman and Upper Chapman brooks, and includes Fisher Creek and a reach of the lower Blackwood River.

McLeod Creek, including its major tributary Rushy Creek, flows from the west of the study area into the lower Blackwood River. The main channels of McLeod Creek and Rushy Creek are approximately 18 km and 8 km respectively. The catchment of the McLeod Creek system is 115 km^2 in total (as defined for this study, see Section 3.2), comprising 92 km^2 for McLeod Creek and 22 km^2 for Rushy Creek (Figure 2).

Chapman Brook, including its major tributary Upper Chapman Brook, flows from the north of the study area into the lower Blackwood River. The main channels of Chapman and Upper Chapman brooks are both approximately 20 km in length. The catchment of the Chapman Brook system is 187 km^2 in total, comprising 70 km^2 for Chapman Brook and 117 km^2 for Upper Chapman Brook (Figure 2). (Note: the assessment of the Chapman and Upper Chapman brooks in this study covered approximately 15 km of the length of each main channel, incorporating 65 km^2 of the Chapman Brook catchment and 94 km^2 of the Upper Chapman Brook catchment, see Section 3.2).

Fisher Creek flows from the north-east of the study area into the lower Blackwood River and is approximately 13 km in length, with a catchment area of 34 km^2.

The reach of the lower Blackwood River included in the study extends from the McLeod Creek confluence to the Fisher Creek confluence. The reach is approximately 12 km in length and has a catchment area of 49 km^2.

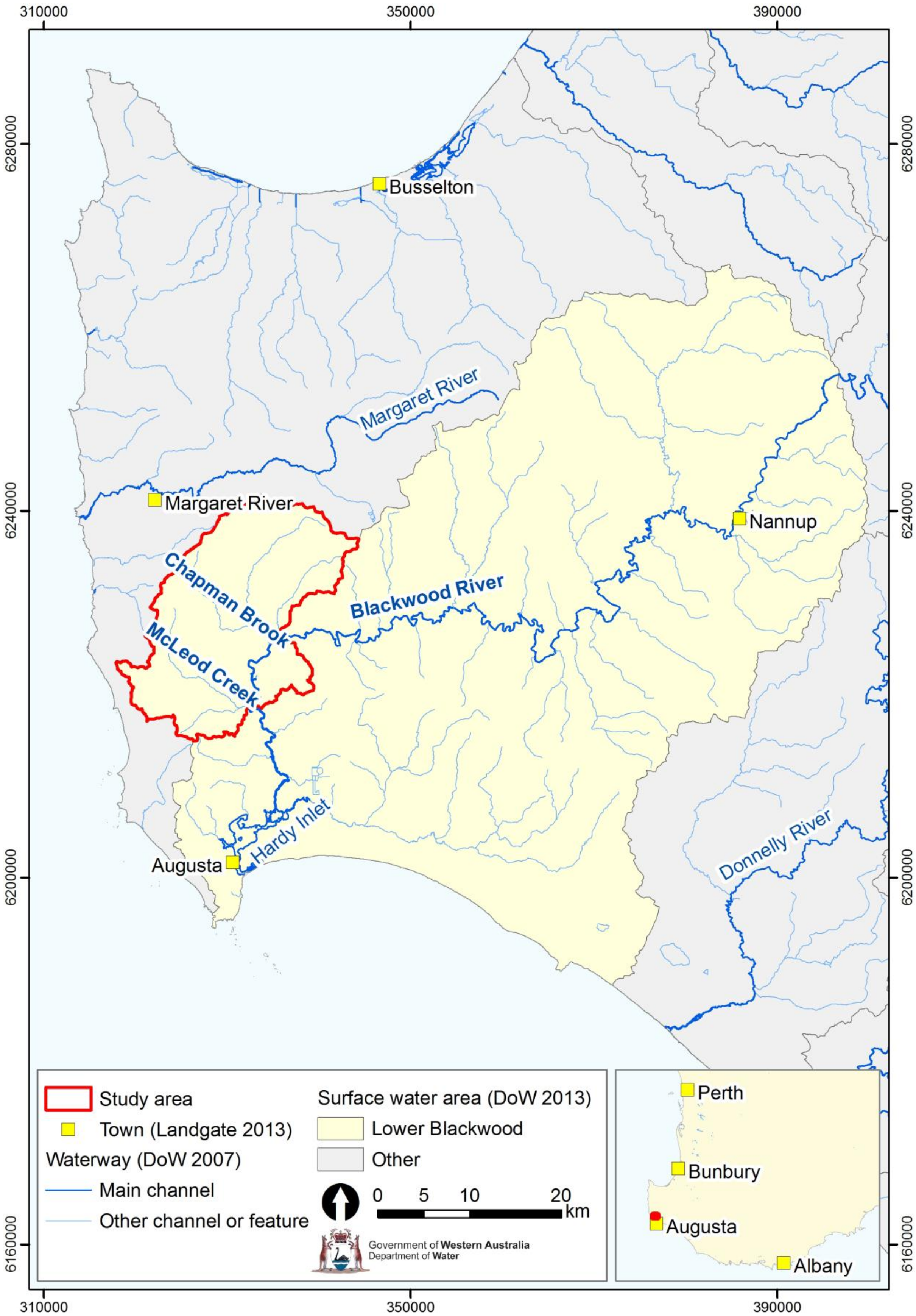


Figure 1 Location of study area

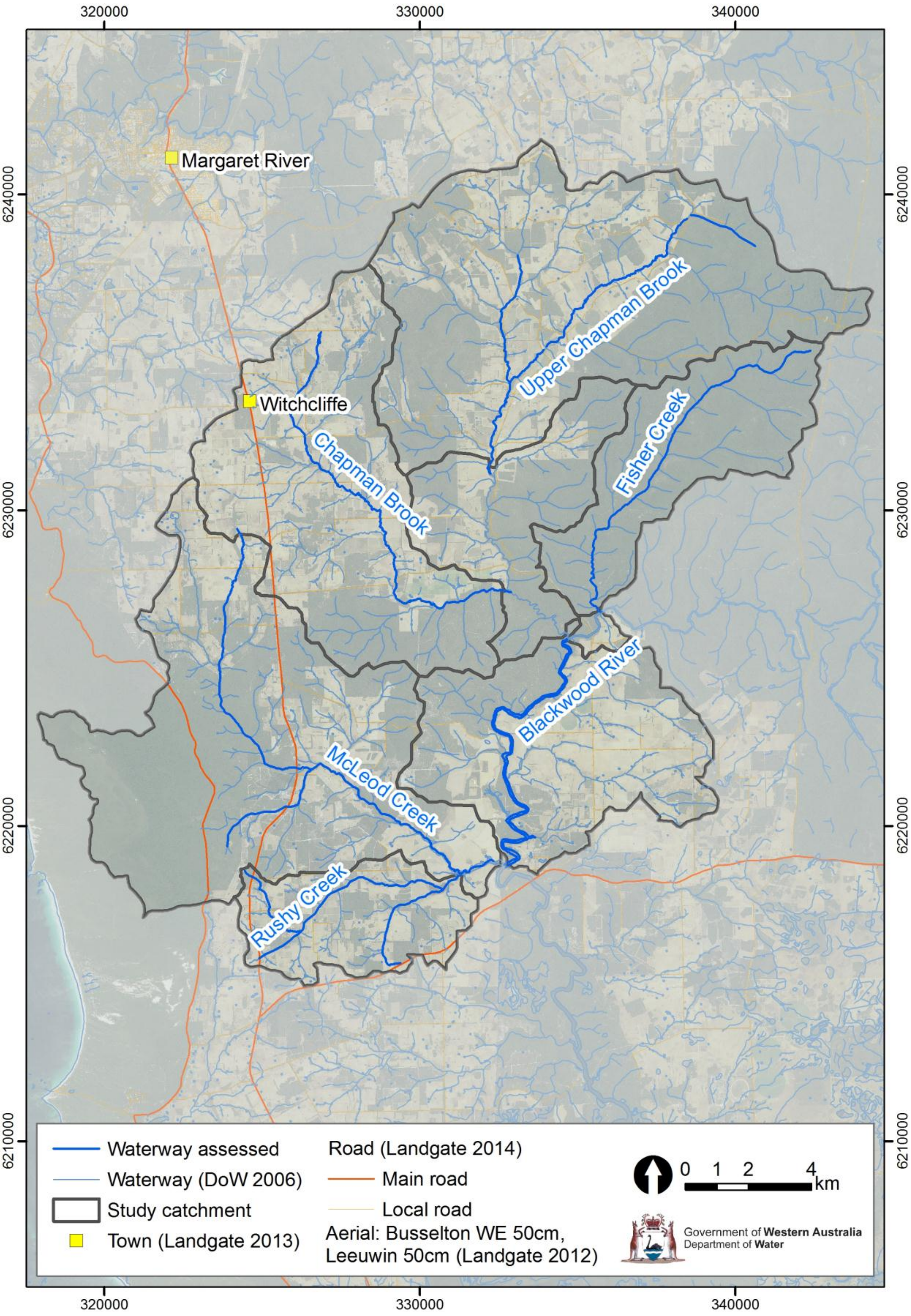


Figure 2 Catchments defined for the study

2.2 Elevation

Elevation ranges from 5 m to 225 m above the Australian Height Datum (AHD) across the study area (spatial data – Landgate 2009, see Appendix Z). The elevation of the headwaters of the main channel is 80 m for McLeod and Rushy creeks, 85 m for Chapman Brook, 100 m for Upper Chapman Brook and 115 m for Fisher Creek. At the downstream end of each main channel the elevation is between 5 and 10 m (Figure 3).

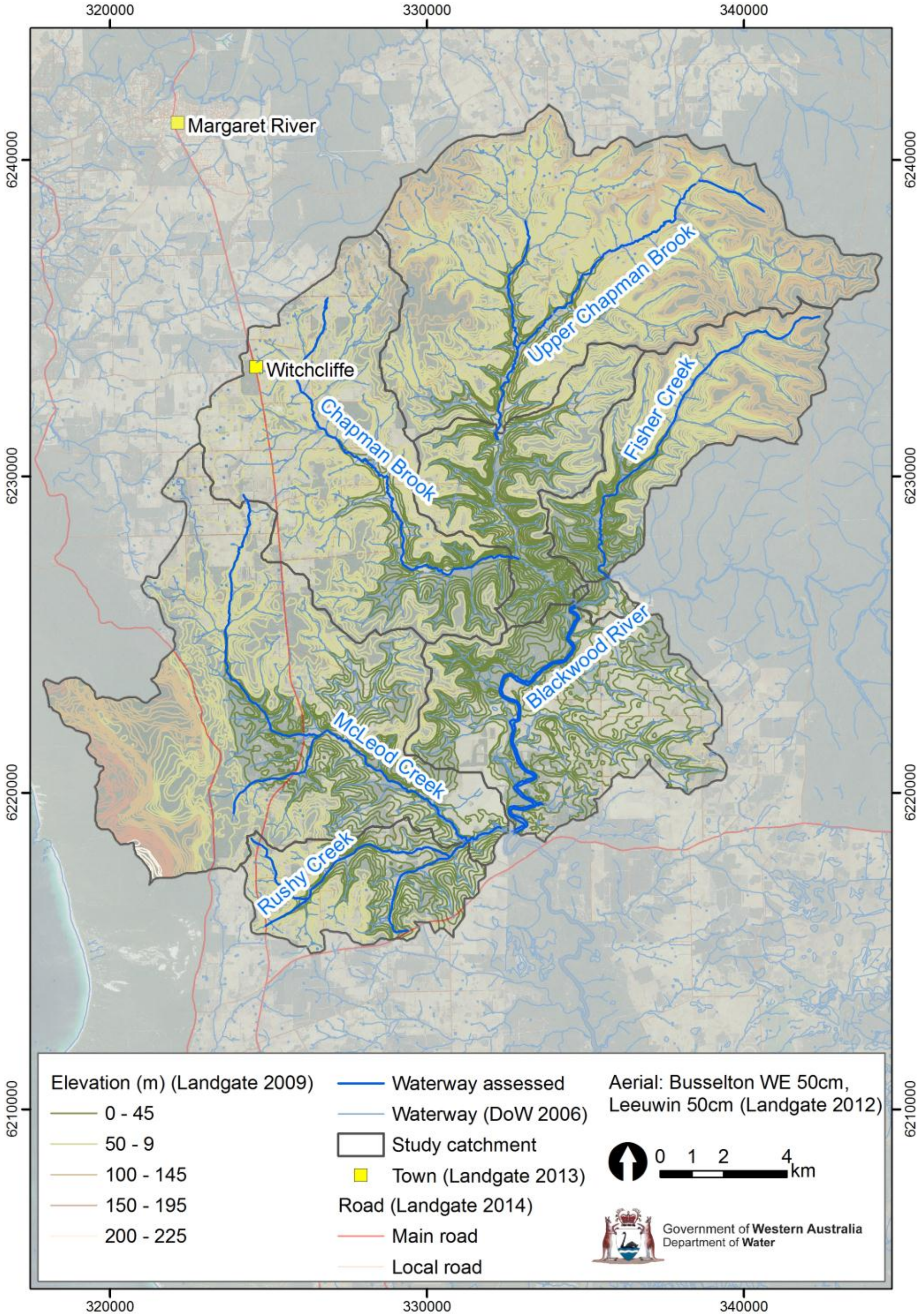


Figure 3 Elevation of the study area

2.3 Geology, hydrogeology and soils

The bedrock geology underlying the study area comprises two tectonic units: the Leeuwin Complex under the western half of the study area, and the Perth Basin under the eastern half. The Dunsborough Fault separates the tectonic units (Lowry 1967) (Figure 4).

The upper reaches of McLeod and Rushy creeks and Chapman Brook are located on the Leeuwin Complex. This unit is a raised block about 1.1 billion years old. It comprises metamorphic rock, including gneiss and granite gneiss and porphyritic granite, beneath lateritic profiles (Tille et al. 2001). The granitic rocks of the Leeuwin Complex give rise to a fractured rock aquifer. In fractured rock aquifers, the rock body is solid, with limited and generally unconnected fractures. Groundwater storage and movement can only occur along these fractures. The fractures are recharged by rainfall and groundwater seepage, and can be fed by surface water springs and streams and underground streams. These may discharge into surface water systems. Overlying the fractured rock aquifer, the surficial aquifer can comprise alluvial and colluvial deposits in river valleys, and dunes and swales in other areas (DoW 2009c).

Fisher Creek, Upper Chapman Brook, and the lower reaches of McLeod and Rushy creeks and Chapman Brook are located on the Perth Basin. This unit is a deep trough of sedimentary rocks including sandstones, siltstones, shale, mudstones and coal (Tille et al. 2001). This eastern half of the study area is located over three main aquifers (described in descending order):

- The Blackwood surficial aquifer comprises a variety of deposits where erosion and weathering of the sediments has occurred (DoW 2007).
- The Leederville aquifer is a multi-layer system comprising discontinuous interbedded sand and clay sequences (DoW 2007) (Figure 4).
- The Lesueur Sandstone and Sue Coal Measures aquifer are managed together. The Lesueur Sandstone aquifer comprises the Sabina and Lesueur sandstone formation, and is greater than 200 m below ground. It is not currently known whether the aquifer discharges into the lower reaches of the Blackwood River (DoW 2007) (Figure 4).

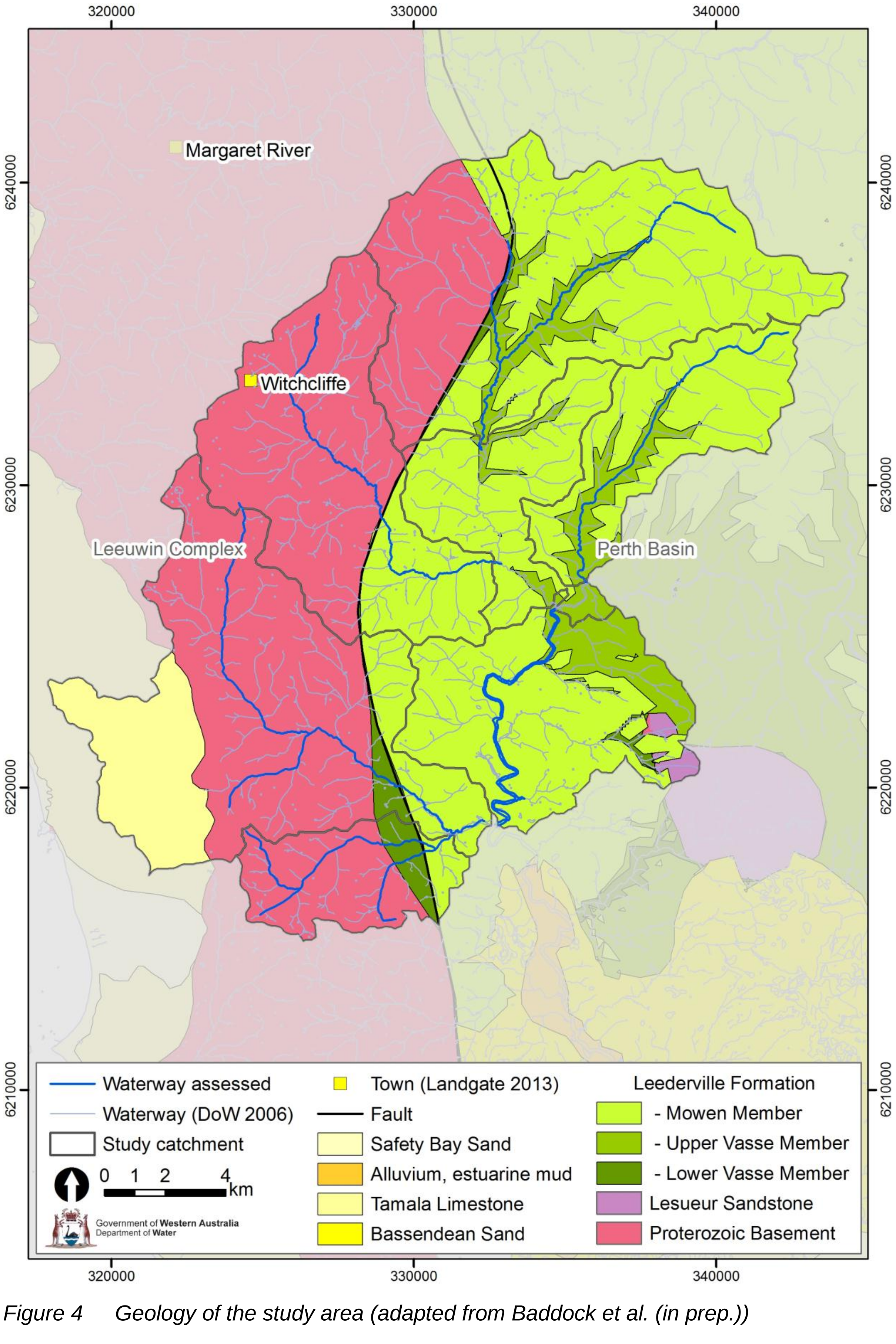


Figure 4 Geology of the study area (adapted from Baddock et al. (in prep.))

Overlying the bedrock geology are a series of soil complexes, which are grouped into three soil-landscape zones, based on geomorphological or geological characteristics (Schoknecht et al. 2004) (Table 1 and Figure 5).

Table 1 Soil-landscape zones and systems of the study area (source: DAFWA soil-landscape map unit database version 5)

Soil-landscape zone		**Soil system**	
Name	**Description**	**Name**	**Description (geology and soil)**
Donnybrook Sunklands zone (214)	Moderately dissected lateritic plateau on Perth Basin sedimentary rocks.	Blackwood Plateau System (214Bp)	Lateritic plateau. Sandy gravel, loamy gravel and deep sand.
		Goodwood Valleys System (124 Gv)	Valleys. Sandy gravel, loamy gravel and deep sand.
		Nillup Plain System (214Np)	Poorly drained plain. Sandy gravel, non-saline wet soil, grey deep sandy duplex, loamy gravel and pale deep sands.
		Treeton Hills System (214Th)	Rises and low hills. Sandy gravel, grey deep sandy duplex and loamy gravel.
Scott Coastal zone (215)	Pleistocene to recent coastal barrier dunes and backplain.	Scott River Plain System (215Sr)	Poorly drained coastal plain. Non-saline wet soil and pale deep sand.
Leeuwin zone (216)	Moderately dissected lateritic plateau on granite.	Cowaramup Uplands System (216Co)	Lateritic plateau. Sandy gravel, loamy gravel and grey sandy duplex.
		Gracetown Ridge System (216Gr)	Limestone ridge. Yellow deep sand and red deep sand.
		Wilyabrup Valleys System (216Wv)	Granitic valleys. Loamy gravel, sandy gravel and loamy earth.

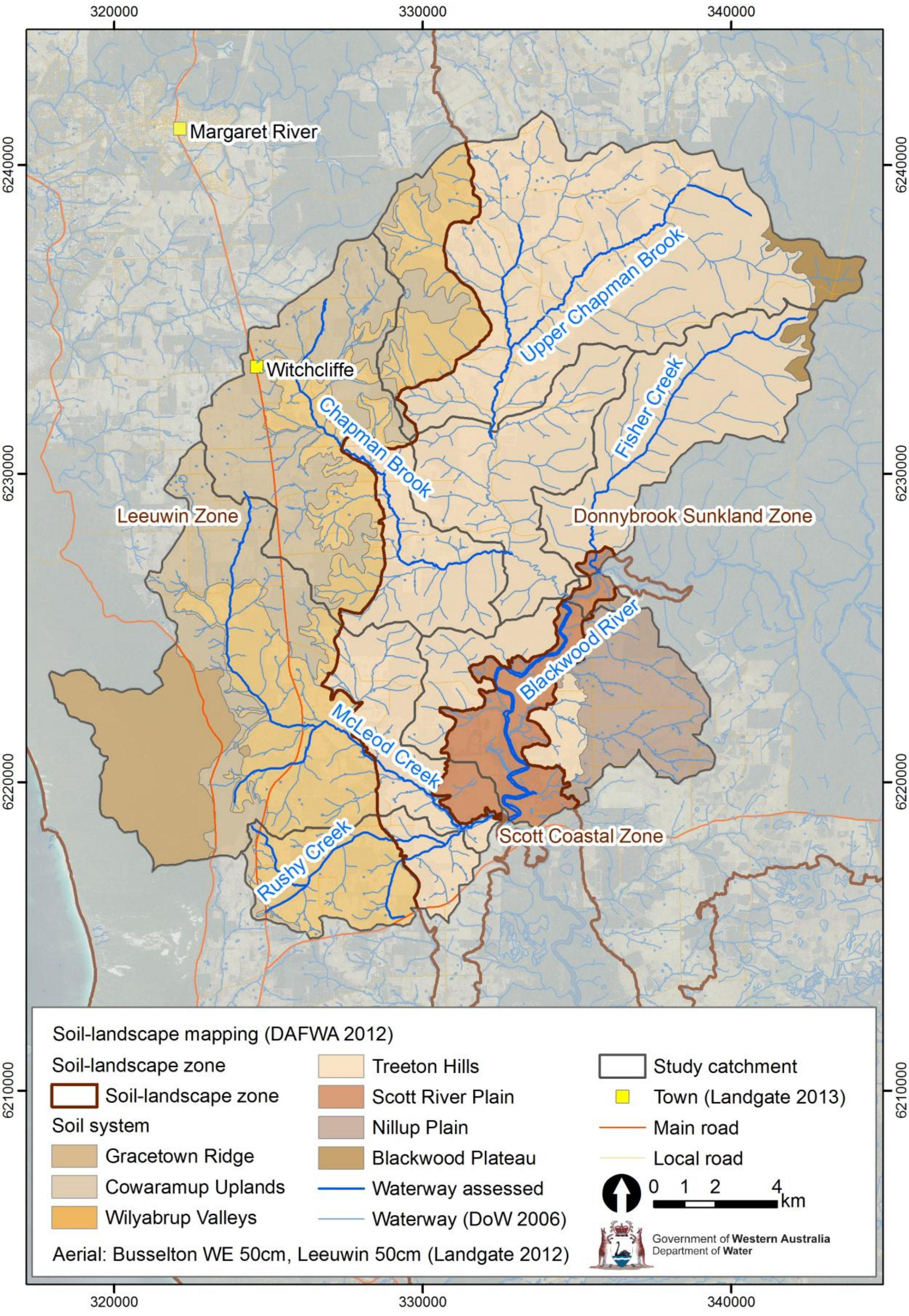


Figure 5 Soil-landscape zones and systems in the study area

2.4 Climate

The study area is within the Whicher region, which has a temperate climate with distinct seasons (wet winter, dry summer). Winter rainfall is typically derived from cold fronts crossing the coast, while summer rainfall events can occur as a result of ex-tropical cyclones arriving from the north-west (DoW 2007).

Climate change

Observed changes

The decline in rainfall across south-west Western Australia since the late 1960s to mid-1970s has been well documented, with the decline being most apparent in the late autumn and early winter months (May, June, July) (for example see IOCI 2012, Hope & Ganter 2010, CSIRO 2009). Hope et al. (2010) suggest a further statistically significant decline in early winter rainfall occurred in 1999–2000, although Durrant (2009) suggests there has not been a further significant reduction in mean annual rainfall compared with the step-change observed in the mid-1970s.

Long-term rainfall data is available for one gauge within the study area: Forest Grove (009547) in the upper catchment of McLeod Creek (Figure 6). Based on the analysis of daily rainfall data up to 2003, Rodgers (2007) suggests that no noticeable decrease in mean annual rainfall occurred in the early 1970s compared with the long-term mean. When updated to 2012, the data shows a 2% reduction in mean annual rainfall for 1975 to 2012, compared with the long-term mean (1929–2012). Mean annual rainfall for the past 12 years (2001–2012) was 7% lower than the mean for 1975 to 2012, and 8% lower than the long-term mean (1929–2012) (Figure 7).

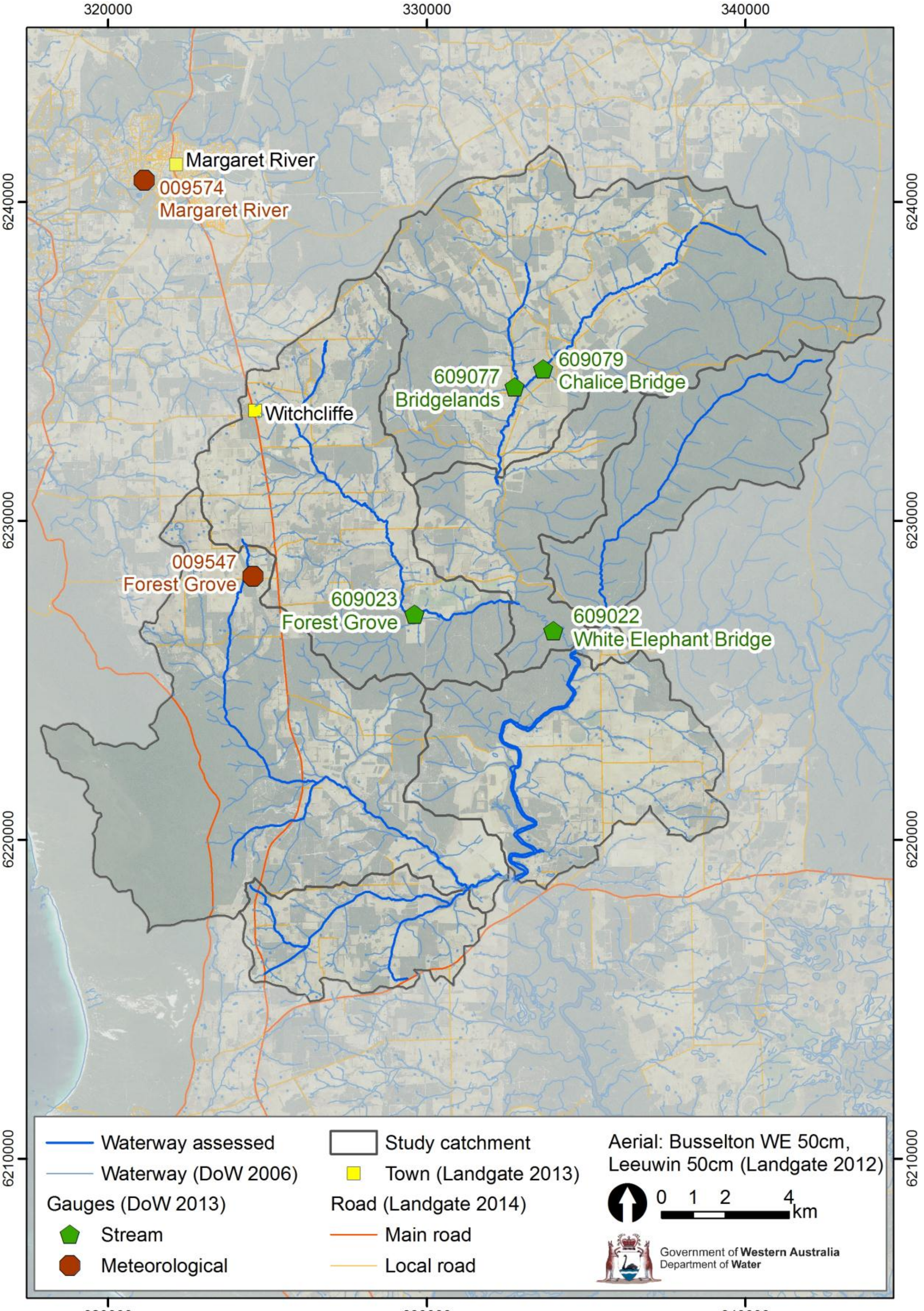


Figure 6 Location of stream flow and rainfall gauging stations

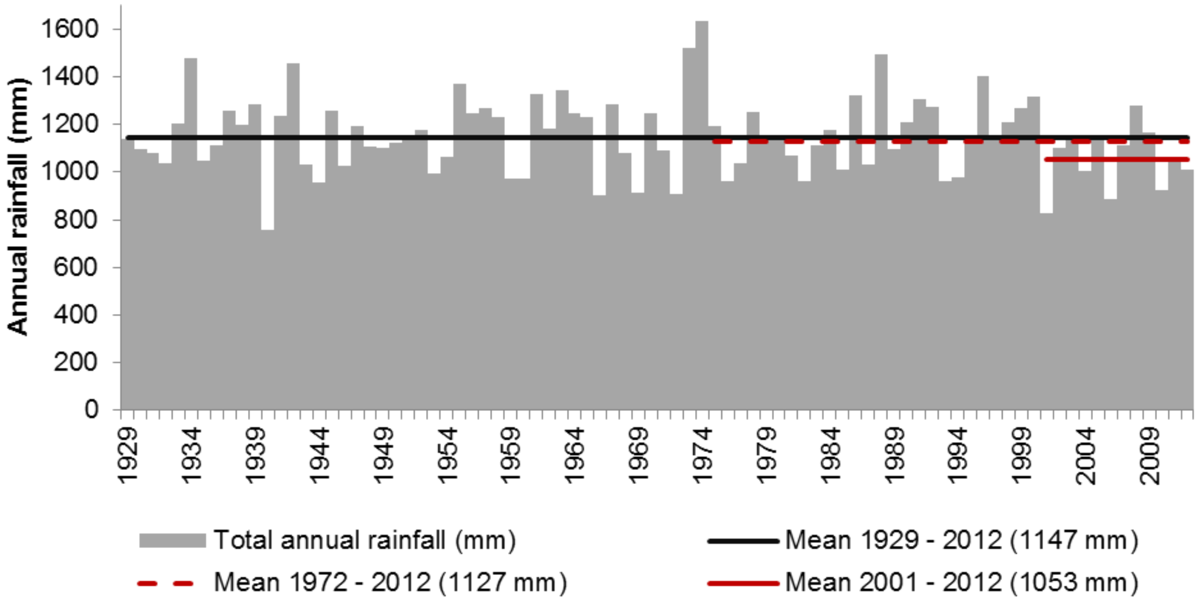


Figure 7 Mean annual rainfall in millimetres at Forest Grove (009547) 1929 to 2012 (source: BoM 2013)

Note: mean analysis periods shown do not represent statistically derived break-points for rainfall trends at this station.

During the same period, monthly rainfall distribution has changed slightly, with a lower proportion of the monthly rainfall occurring in March to July since 1975 compared with the long-term record (1929–2012) and a higher proportion occurring in August, September and November (Figure 8).

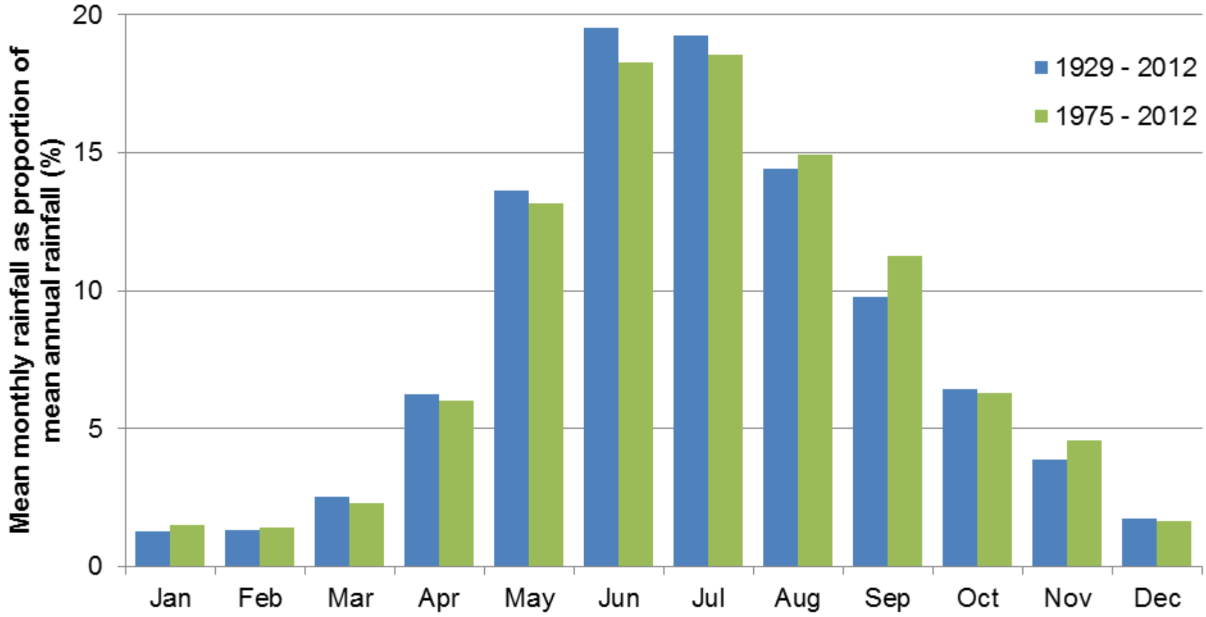


Figure 8 Mean monthly rainfall as a proportion of mean annual rainfall (%) at Forest Grove (009547) 1929 to 2012 (source: BoM 2013)

The nearest gauge with long-term rainfall records outside the study area is Margaret River (009574), 7 km north-west of the study area (Figure 6). At this station, mean annual rainfall has declined by 8% for the period 1975 to 2012 compared with the long-term mean (1929–2012) (Figure 9). Mean annual rainfall for the past 12 years (2001–12) was 8% lower than the mean for 1975 to 2012, and 16% lower than the long-term mean (1929–2012) (Figure 9).

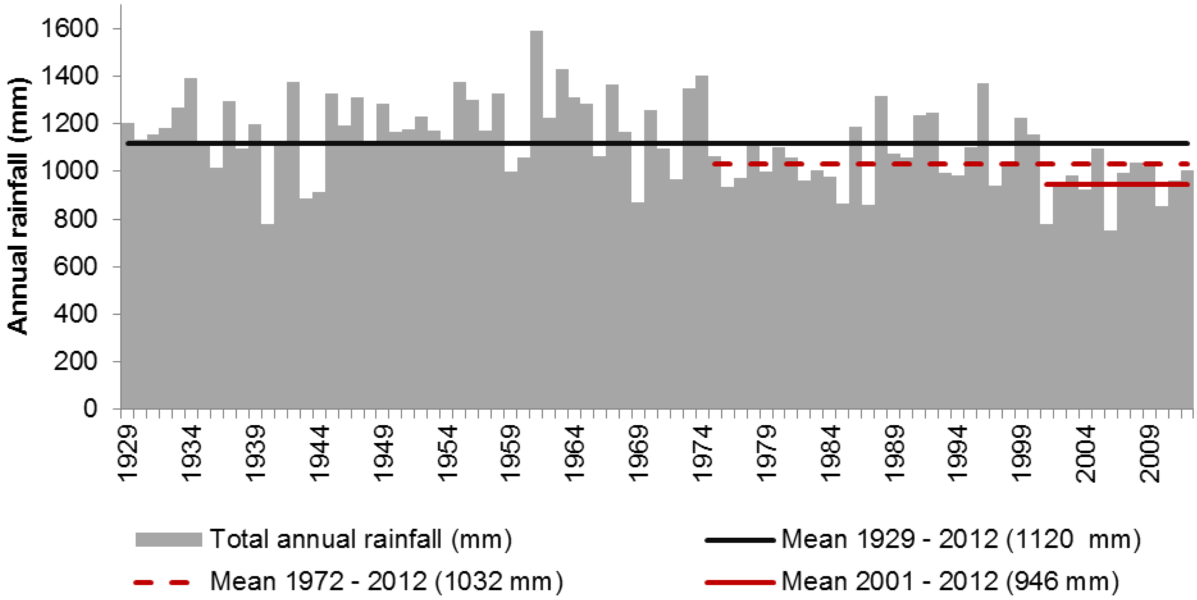


Figure 9 Mean annual rainfall in millimetres at Margaret River (009574) 1929 to 2012 (source: BoM 2013)

Note: mean analysis periods shown do not represent statistically derived break-points for rainfall trends at this station.

Monthly rainfall distribution has also changed slightly at Margaret River, with a lower proportion of the monthly rainfall occurring in March to July since 1975 compared with the long-term record (1929–2012) and a higher proportion occurring in August, September and November (Figure 10).

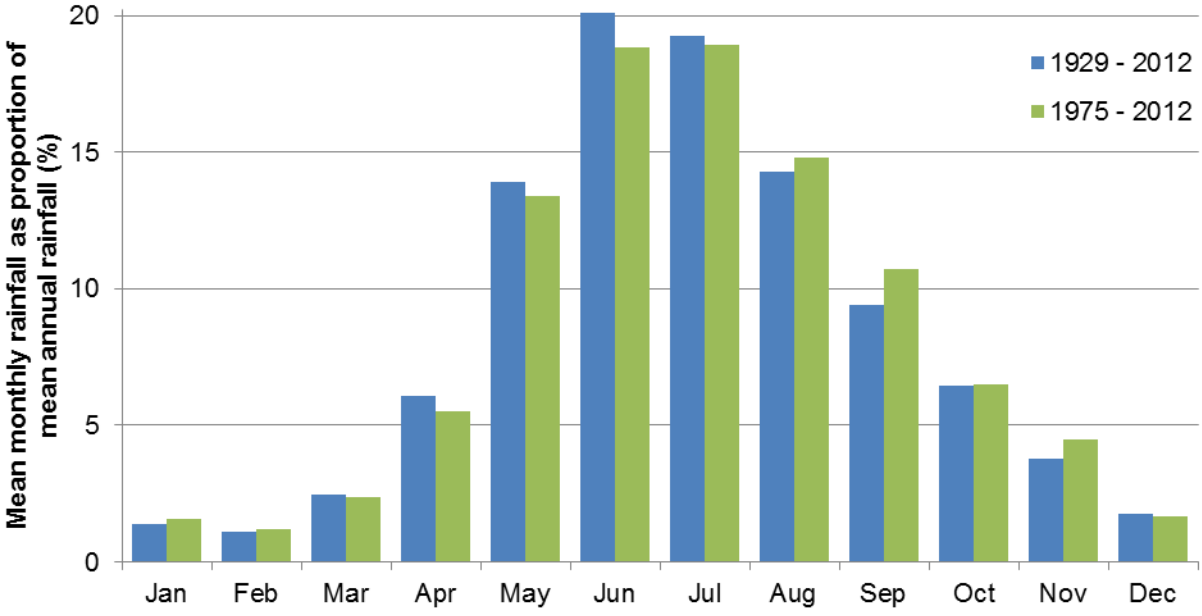


Figure 10 Mean monthly rainfall as a proportion of mean annual rainfall (%) at Margaret River (009574) 1929 to 2012 (source: BoM 2013)

Future predictions

Climate change modelling by CSIRO (2009) predicts that mean annual rainfall in the Lower Blackwood modelled basin area will be between 2 and 14% lower in 2030 than for the period 1975 to 2007 (scenarios C-wet and C-dry respectively).

For the same basin area and scenarios, the projected decline in mean annual runoff for 2030 is between 10 and 42% of mean annual runoff for 1975 to 2007 (CSIRO 2009).

2.5 Surface water

Chapman Brook

The Department of Water has measured flow at two gauges on the Chapman Brook since mid-1995: Forest Grove (609023) approximately 4 km upstream of the confluence with the Upper Chapman Brook, and White Elephant Bridge (609022) approximately 2 km downstream of the confluence with the Upper Chapman Brook (Figure 6). Mean annual flow for the period 1996 to 2012 was 12 720 ML and 42 320 ML respectively.

Mean annual flow at White Elephant Bridge was estimated for the years from 1962 to 1995 to support trend analysis (see DoW 2007). Mean annual flow in the period 1975 to 2012 was 15% lower than the long-term mean (1965–2012). Mean annual flow for the last 12 years (2001–12) was 40% lower than the mean for 1975 to 2012 (Figure 11).

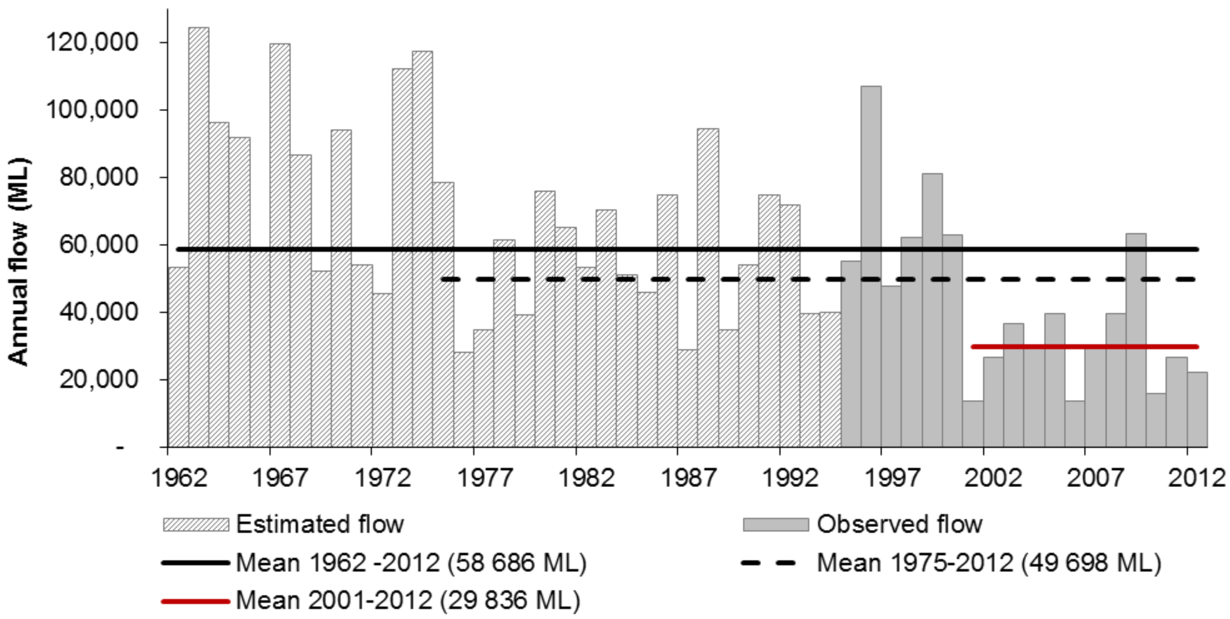
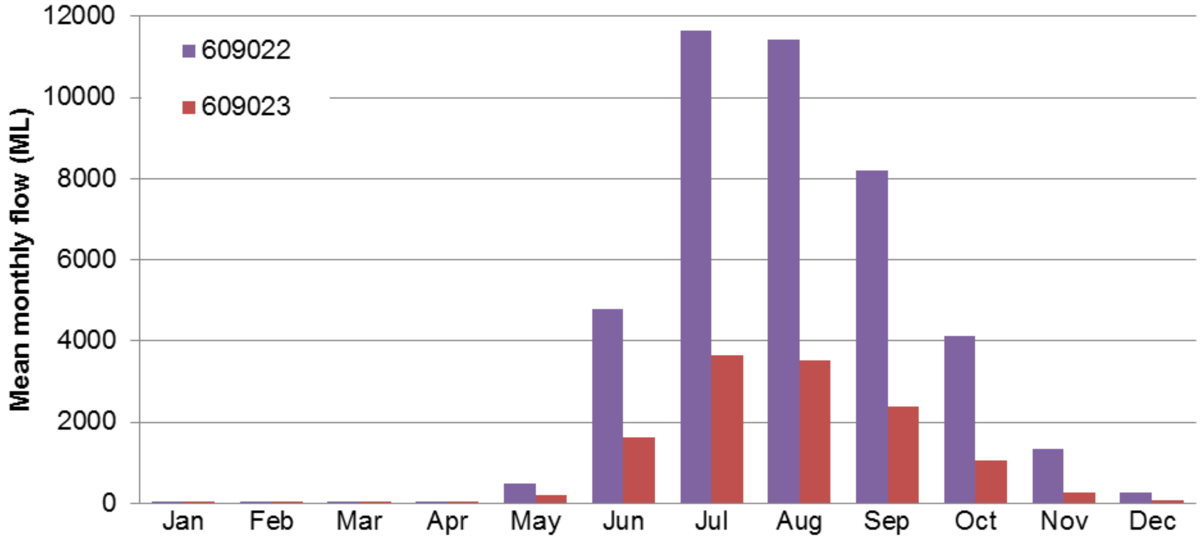


Figure 11 Mean annual flow (in megalitres) estimated and observed for Chapman Brook (at White Elephant Bridge, 609022) 1962 to 2012

Note: mean analysis periods shown do not represent statistically derived break-points for flow trends at this gauge.

Flow in the Chapman Brook at White Elephant Bridge is seasonal, with 90% of the annual flow occurring between June and October, based on analysis of data from 1995 to 2005 (Rodgers 2007). A similar seasonal pattern can be seen at Forest Grove (Figure 12).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
609022	26	8	13	24	485	4774	11637	11439	8192	4126	1348	251
609023	1	1	1	4	189	1607	3637	3534	2372	1040	276	60

Figure 12 Mean monthly flow (in megalitres) in Chapman Brook at White Elephant Bridge (609022) and Forest Grove (609023) 1996 to 2012

For Chapman Brook (at White Elephant Bridge) the continuous flow period data (the main flow period when daily flow is greater than 0 ML, DoW 2007), show that flow is seasonal, generally starting in April or May and stopping in January (Figure 13).

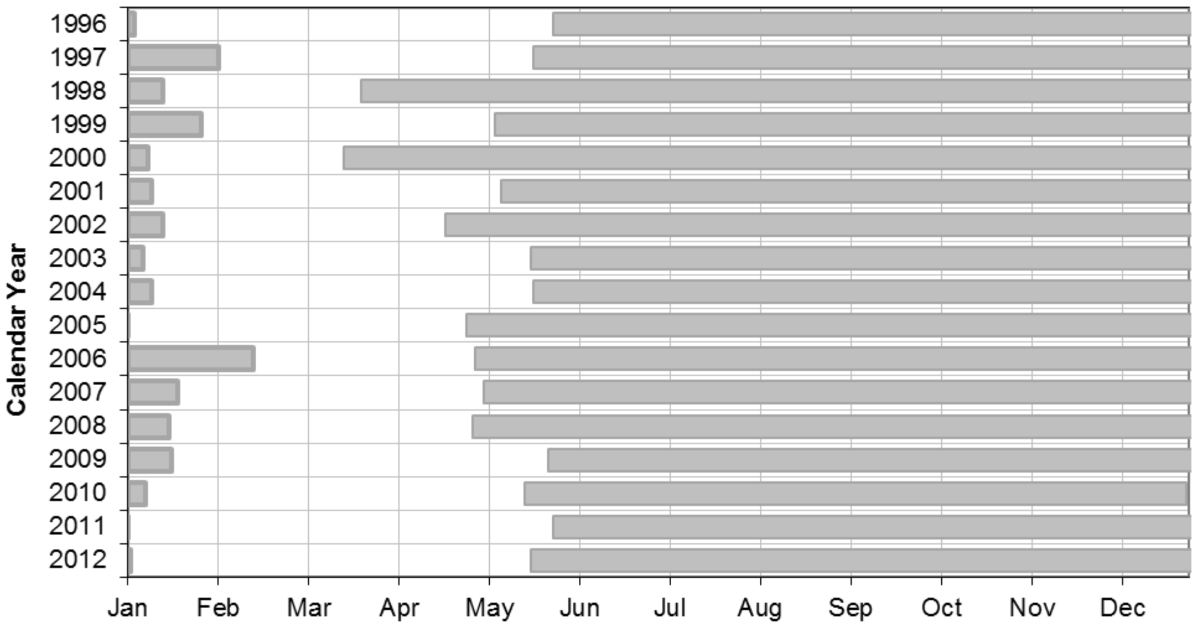


Figure 13 Continuous flow period observed for Chapman Brook (at White Elephant Bridge, 609022) 1996 to 2012

Given Chapman Brook's lower reaches overlie the sedimentary aquifers of the Perth Basin (Figure 4), it is possible that groundwater sources contribute to surface water flows, however insufficient data are available to determine the connectivity with certainty (Rodgers 2007).

Upper Chapman Brook

Stream gauging data for the Upper Chapman Brook are only available for a limited time period. Data collected between May 2011 and December 2012 at Bridgelands (609077) and Chalice Bridge (609079) show that flow for that period followed a seasonal pattern, with low flows or discontinuation of flow between December and May (Figure 14). Further temporal data is required to confirm whether the flow regime seen in 2011–12 is typical for the Upper Chapman Brook.

The Upper Chapman Brook overlies the sedimentary aquifers of the Perth Basin (Figure 4). As discussed for the Chapman Brook, it is possible that groundwater sources contribute to surface water flows in summer, although this has not been confirmed to date.

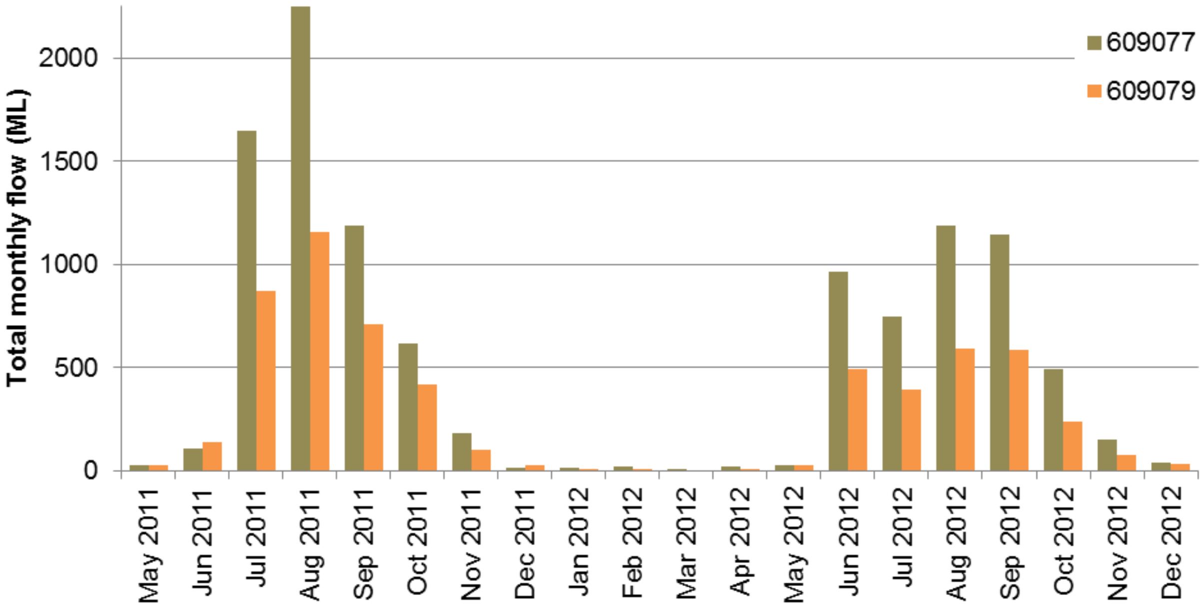


Figure 14 Total monthly flow (in megalitres) in Upper Chapman Brook at Bridgelands (609077) and Chalice Bridge (609079) 2011 to 2012

McLeod and Rushy creeks

There are no Department of Water stream gauging stations on the McLeod and Rushy creeks. Hydrological modelling of these tributaries was undertaken as part of the Hardy Inlet Stage 2 WQIP for the lower Blackwood River (DoW in prep.). The model estimated mean annual flow for 1975 to 2011 to be 16.6 ML for McLeod Creek and 5.7 ML for Rushy Creek (DoW in prep.).

Given that the upper and mid reaches of the McLeod and Rushy creeks are located on the fractured rock aquifers of the Leeuwin Block (Figure 4), it is unlikely that groundwater contributes significantly to surface water flows in these reaches during summer. Surface–groundwater connectivity is more likely to occur in the lower reaches that overlie the sedimentary aquifers of the Perth Basin.

Fisher Creek

There are no stream gauging stations on Fisher Creek. Hydrological modelling of Fisher Creek has been completed as part of the Hardy Inlet Stage 2 WQIP for the lower Blackwood River (DoW in prep.). The model estimated mean annual flow for 1975 to 2011 to be 4.6 ML.

As with Upper Chapman Brook, Fisher Creek overlies the sedimentary aquifers of the Perth Basin (Figure 4) and hence it is possible that surface–groundwater connectivity may occur.

Lower Blackwood River

The annual average flow in the Blackwood River at Hut Pool (609019), approximately 11 km upstream of the confluence with Fisher Creek (Figure 6), for 1983 to 2012 was 492 393 ML.

Mean monthly flow for this period ranged from 2051 ML/month in January to 144 921 ML/month in August (Figure 15).

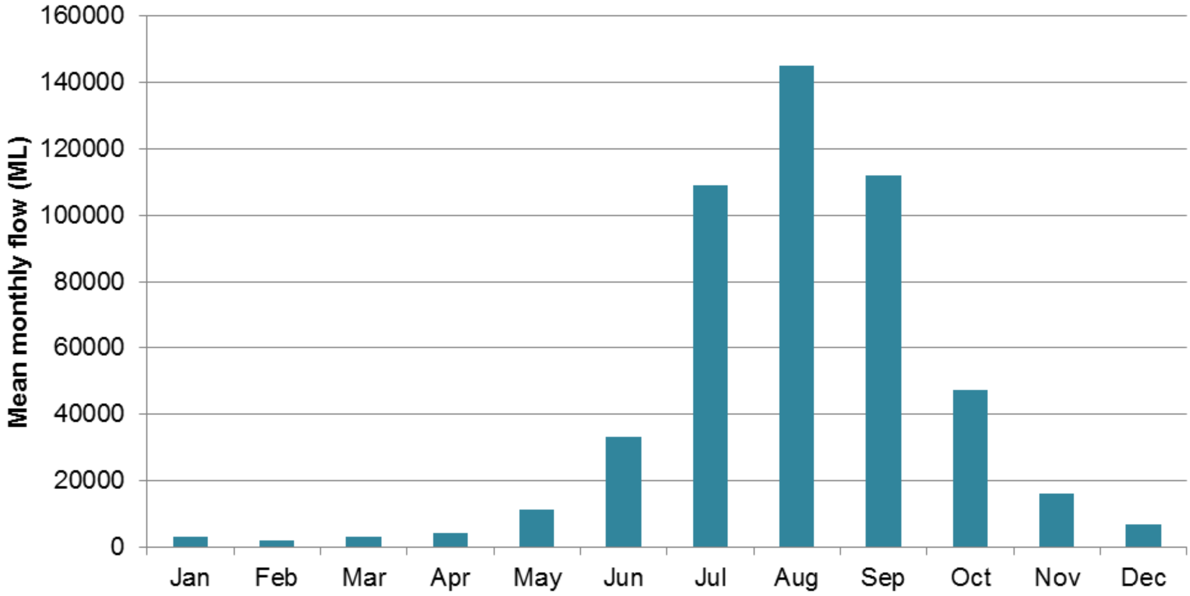


Figure 15 Mean monthly flow (in megalitres) in the lower Blackwood River at Hut Pool (609019) 1984 to 2012

2.6 Land use

Based on the 2007 land use mapping (see Appendix Z), just over half the study area (58%) was covered by conservation and other minimal uses, while a third (34%) was used for grazing. Intensive and irrigated agriculture covered 4% of the study area, plantation forestry covered 3% and urban, mining and transport uses covered 2% (Figure 16).

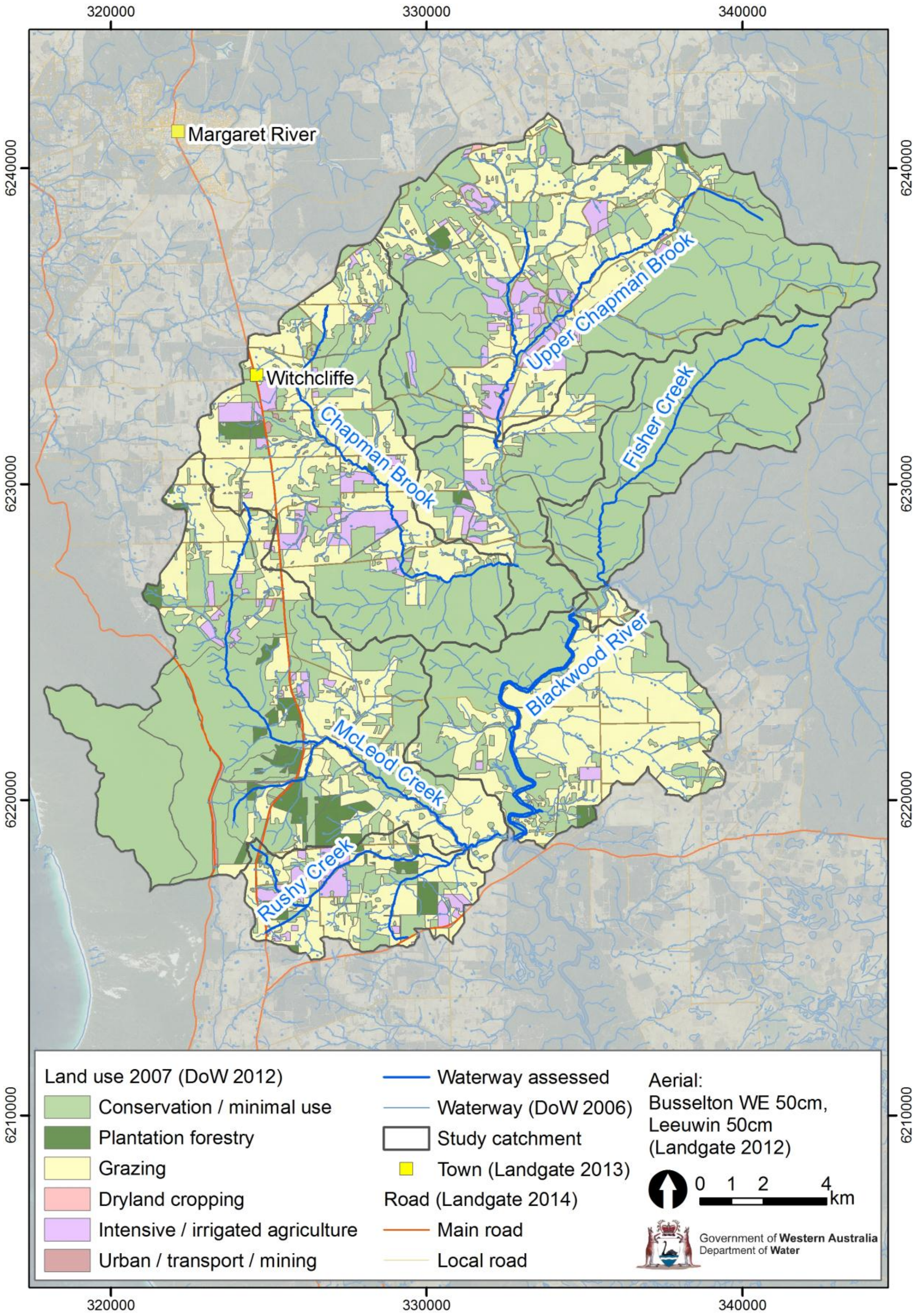


Figure 16 Land use in the study area at 2007

2.7 Ecological value

The lower Blackwood River and a number of its tributaries, including McLeod Creek and Chapman Brook, is a high ecological value aquatic ecosystem (HEVAE) (Commonwealth of Australia 2008, 2011). The lower Blackwood River area is also the subject of a proposed nomination under the Convention on Wetlands of International Importance (known as the Ramsar convention). This includes the mid catchment of McLeod Creek and the lower catchment of Chapman Brook (Strehlow & Cook 2010).

Flora

Based on datasets of native vegetation extent at 2011 and pre-European vegetation (see Appendix Z), the following native vegetation occurs the study area (Figure 17).

- Native vegetation covers approximately 60% of the McLeod Creek catchment and is dominated by medium height jarrah-marri forest in the eastern and central parts of the catchment. The western part of the catchment is covered by tall karri forest (*E. diversicolor*) and acacia shrubland (*Acacia decipiens*). Small areas of low paperbark woodland (*Melaleuca* sp.) (1.1 km^2) and medium height jarrah woodland (1.3 km^2) also occur in the catchment, along with very small areas (less than 0.5 km^2) of six other vegetation groups.
- Approximately 24% of the Rushy Creek catchment is covered by native vegetation comprising medium height jarrah-marri forest and tall karri forest (*E. diversicolor*).
- Native vegetation covers approximately 41% of the Chapman Brook catchment defined for this project. This is dominated by medium height jarrah-marri forest with a small area (less than 0.5 km^2) of tall karri forest (*Eucalyptus diversicolor*).
- The Upper Chapman Brook catchment (as defined for this project) has approximately 58% native vegetation cover, which is dominated by medium height jarrah-marri forest, with small areas (less than 0.5 km^2) of low jarrah woodland and tall karri forest (*E. diversicolor*).
- Approximately 98% of the Fisher Creek catchment is covered by native vegetation which is dominated by medium height jarrah-marri forest. Small areas (less than 1.5 km^2) of low jarrah woodland and medium woodland of flooded gum (*Eucalyptus rudis*) and blackbutt (with some bullich, jarrah and marri) also occur in the catchment.
- Native vegetation covers approximately 39% of the catchment of the lower Blackwood River defined for this study. It is dominated by medium height jarrah-marri forest. A small area (3.1 km^2) of medium height woodland fringes the Blackwood River, comprising flooded gum (*Eucalyptus rudis*) and blackbutt with some bullich, jarrah and marri. A small part of the catchment (1.2 km^2) is covered by low paperbark woodland (*Melaleuca* sp.).

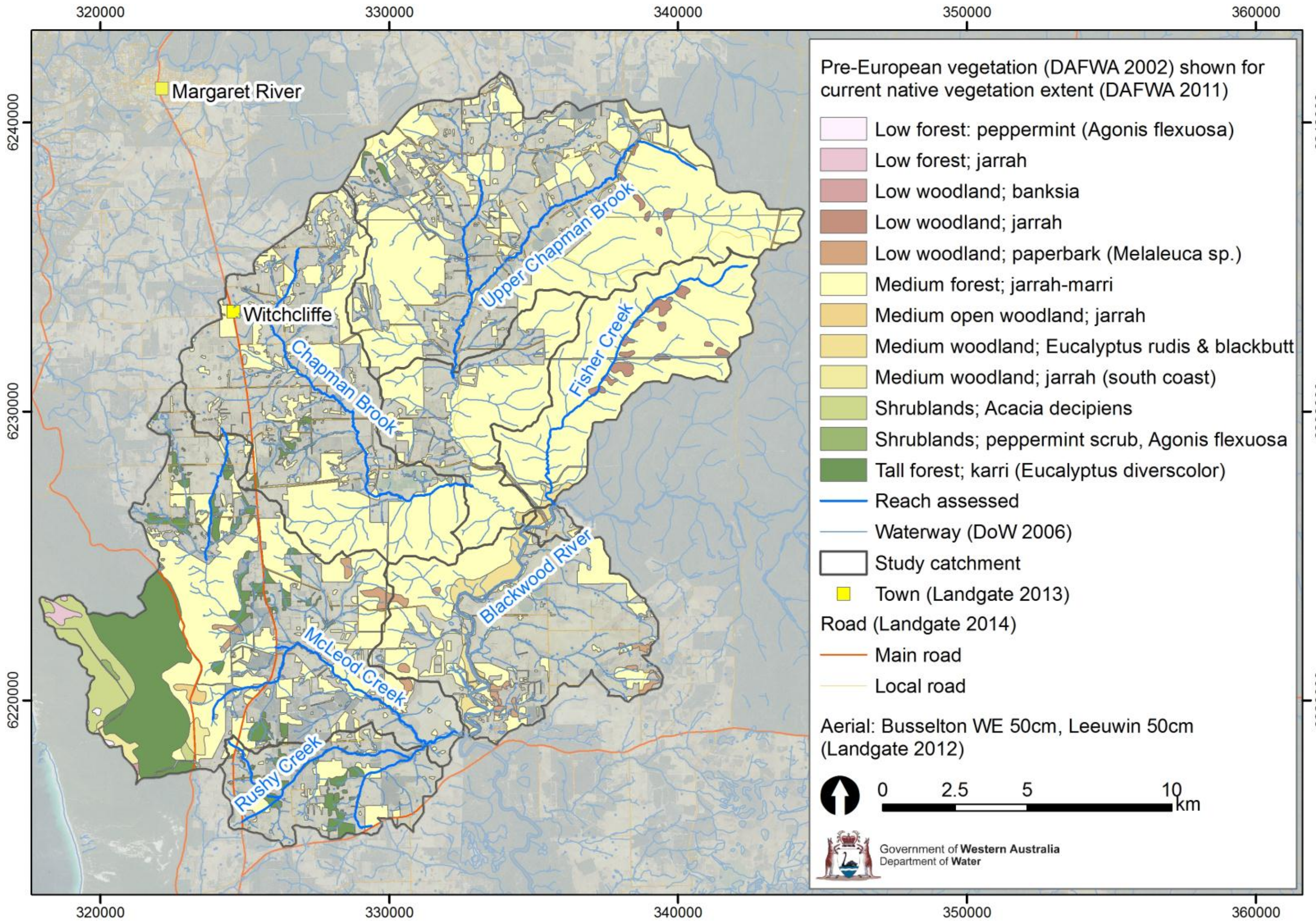


Figure 17 Extent of native vegetation in the study area at 2011

A number of flora species listed as Threatened under the *Wildlife Conservation Act 1950* and listed as Priority by DPaW occur in the study area, based on a search of DPaW's Threatened (Declared Rare) and Priority Flora database and the WA Herbarium Specimen database conducted in May 2013 (a full list is provided in Appendix B). This includes one Threatened species, *Reedia spathacea* (sedge).

Fauna

A number of fauna species listed as Threatened and Priority fauna species occur in the study area, based on a search of DPaW's Threatened Fauna database conducted in May 2013 (a full list is provided in Appendix B), including:

- one amphibian: *Geocrinia alba* (white-bellied frog) listed as Threatened (fauna that is rare or is likely to become extinct), which has a limited range of approximately 130 km^2 between Margaret River and Witchcliffe (Tyler et al. 2000 cited in WRM 2007a)
- one fish: *Galaxiella munda* (Western mud minnow) listed as Threatened
- 19 bird species, including five species listed as Threatened
- 14 mammal species, including 10 species listed as Threatened.

WRM (2007a, 2008a, b) reviewed the ecological value of Chapman Brook and found a number of species of amphibians, reptiles, birds and mammals. The water-dependent ecological values are summarised in Table 2.

Table 2 Water-dependent ecological values of Chapman Brook (WRM 2008b)

Aquatic macroinvertebrates	89 macroinvertebrate taxa known 13 species endemic to the south-west Freshwater mussel, *Westralunio carteri*
Freshwater crayfish	Smooth marron, *Cherax cainii* Gilgie, *Cherax quinquecarinatus* Koonac, *Cherax preissii*
Turtle	Long-necked turtle, *Chelodina oblonga*
Fish	Western pygmy perch, *Nannoperca vittata* Western minnow, *Galaxias occidentalis* Nightfish, *Bostockia porosa* Goby, *Pseudogobius olorum* Lamprey, *Geotria australis*
Frogs	White-bellied frog, *Geocrinia alba* Western green frog, *Litoria moorei*
Riparian fauna	Water rat, *Hydromys chrysogaster* Tiger snake, *Notechis scutatus* Mourning skink, *Egernia luctuosa*

A review of the ecological value specific to the McLeod Creek system and Fisher Creek have not been documented to date (McLeod Creek is included in the broadscale ecological character description of the proposed Ramsar wetland nomination area – Strehlow & Cook 2010).

Previous sampling of fish and crayfish in the study area is limited to four studies: the native and exotic species found are listed in Appendix G.

Threatened and Priority ecological communities

Reedia swamps (rushes and sedges: *Reedia spathacea* – *Empodisma gracillimum* – *Sporadanthus rivularis*) listed as Priority 1 (poorly known taxa) in DPaW's Threatened Ecological Communities database (search conducted May 2013, Appendix B). *R. spathacea* has a limited distribution and provides the main live biomass in the areas where it occurs, hence is considered a keystone species. It is restricted to oligotrophic and permanently waterlogged wetlands, and provides habitat for other biota such as *Geocrinia alba* (Commonwealth of Australia 2008).

2.8 Further information

Further information about the characteristics (geology, hydrogeology, climate, surface and groundwater resources, value, social and cultural values) of the study area can be found in descriptions of the lower Blackwood River catchment in various documents including:

- *Whicher area surface water allocation plan* (DoW 2009a) and supporting documents
- *South West groundwater areas allocation plan* (DoW 2009b) and supporting documents
- *Ecological values of seven south-west rivers* (WRM 2007a) and associated aquatic fauna sampling (WRM 2008a)
- *Ecological character description of the tributaries of the lower Blackwood River, proposed Ramsar site nomination* (Strehlow & Cook 2010).

3 Methods

3.1 Overview of South West Index of River Condition

River health was comprehensively assessed using the South West Index of River Condition (SWIRC) developed by the Department of Water (Storer et al. 2011a, b). The SWIRC provides a suite of standardised methods for collecting field and desktop data, as well as protocols for analysing the data. Data analysis includes a standardised scoring system for a series of indices, sub-indices and components to allow comparability of results between river systems across south-west Western Australia.

In addition to regional comparability, the SWIRC scoring system complies with the national Framework for the Assessment of River and Wetland Health (FARWH) and can be used to generate data for national comparison and reporting purposes.

The SWIRC comprises six key ecological themes representing ecological integrity: catchment disturbance, hydrological change, fringing zone, physical form, water quality and aquatic biota. Each theme is divided into a series of sub-themes and components that can be used to meet specific assessment objectives. The current SWIRC themes, sub-themes and components are listed in Table 3. (Note: the SWIRC is continually developing and may include additional sub-themes and components in the future).

The scale of assessment (site, reach or reach catchment) and type of data collection (field or desktop) are indicator-specific (Table 3), based on data requirements to measure condition and availability of existing relevant data.

Table 3 SWIRC themes, sub-themes and components, scale of assessment and data collection type

Theme	Sub-theme	Component	Scale	Data collection
Catchment disturbance (CD)	Land use	–	Catchment of reach	Desktop
	Land cover change	–	Catchment of reach	Desktop
	Infrastructure	–	Catchment of reach	Desktop
Hydrological change (HC)	Flow stress ranking	Low flow High flow Proportion of zero flow Monthly variation Seasonal period	Catchment of creek/brook	Desktop
	Farm dams[1]	Farm dam density Farm dam development	Catchment of creek/brook	Desktop
Fringing zone (FZ)	Extent of fringing zone	Fringing zone width Fringing zone length	Reach	Desktop
	Nativeness	Ground cover layer Shrub layer	Site	Field
Physical form (PF)	Artificial channel	–	Reach	Desktop
	Longitudinal connectivity	Major dams Minor dams Gauging stations Road and rail crossings	Reach	Desktop
	Erosion	Extent of erosion Bank stability	Site	Field
Water and sediment quality (WSQ)	Nitrogen	–	Site	Field
	Phosphorus	–	Site	Field
	Turbidity	–	Site	Field
	Diel dissolved oxygen	–	Site	Field
	Diel temperature	–	Site	Field
	Salinity	–	Reach	Desktop
	Non-nutrient contaminants[1]	–	Site	Field
Aquatic biota (AB)	Macroinvertebrates	–	Site	Field
	Fish and crayfish	Expectedness Nativeness	Site	Field

Notes:

[1] These sub-themes do not currently have a scoring protocol in place (i.e. there is no sub-index relating to these sub-themes, hence they do not appear in Figure 19).

The table reflects the current structure of the SWIRC – this may change in the future as further indicators are developed.

In addition to the data gathered under each theme, the SWIRC assessment includes contextual field observations such as aquatic habitat, channel characteristics, erosion management, vegetation and barriers to connectivity. In addition, in February 2013, ad-hoc observations of flow conditions were made (see Section 3.3).

3.2 Site selection, reach and catchment definition

Under the SWIRC protocols, data are collected at three scales: site, reach and reach catchment (Table 3). The process of selecting sites and defining reaches and catchments was designed to meet the study's three objectives, as described below.

To meet objective one '*provide an assessment of river health that will serve as a baseline against which future change can be measured, particularly in evaluation of restoration areas and for assessing impacts of land management practices*':

- Eleven sites were chosen in consultation with SWCC, incorporating past and future restoration areas and various land management practices, along with several reference sites (Table 4, Figure 18).
- Ten reaches were defined, one for each site (except the Blackwood River sites (BLA15 and BLA16) which were included in a single reach given they were so close to each other). Reaches were defined based on site characteristics and associated broad variability in land use (visible in aerial photography). For example, where a site was located within national park, the start and end of the reach were defined by the boundary of the conservation area.

To meet objective two '*provide river health data to support the development of a river action plan for the McLeod and Rushy creeks':*

- A further eight reaches were defined (in addition to those defined for objective one) reflecting broad variability in land use (visible in aerial photography).
- One site was selected on each of the eight additional reaches to represent conditions of the reach, with consideration given to accessibility (Table 4, Figure 18).

Objective three '*provide river health data (and establish river health monitoring sites) to inform allocation decisions and contribute to the Stage 2 WQIP for the Hardy Inlet*' was met through data collection across sites and reaches outlined above.

The study area was divided into catchments, based on the reaches (Figure 18); this was done in conjunction with the catchment definition process for the Stage 2 Hardy Inlet WQIP (DoW in prep.). Geographical information systems (GIS) software (Environmental Systems Research Institute (ESRI) ArcGIS spatial analyst tool) was used to define the boundaries based on stream topography and landforms, calculated from a 20 m resolution digital elevation model (DEM) which was generated from the Statewide Topographic Contours dataset (Appendix Z).

(Note: in general the outlet of each catchment corresponded with the end of each reach, however in some cases the outlet did not match – this is an artefact of the GIS process, caused by the difference in the spatial resolution of the streamlines generated from the DEM and the reach dataset).

Due to the nature of the reach and catchment definition process approximately 4 km of the downstream end of the Chapman and Upper Chapman brooks were not included in the assessment (Figure 18).

Photographs of the sites are provided in Appendix C.

Table 4 Site purpose and location, reach length and catchment size

River	Site & reach code	Assessment for future evaluations (objective 1)	Assessment for RAP (objective 2)	Reach length (km)	Reach catchment area (km^2)
McLeod Creek	MRAP1		X	2.5	3.1
	MRAP2		X	2.5	15.3
	MC02	X – control site	X	4.5	35.6
	MRAP8		X	4.2	6.5
	MCLEOD		X	7.0	28.0
	MC10	X – restoration site	X	1.5	3.7
Rushy Creek	RRAP9		X	3.1	2.7
	RRAP6		X	6.0	10.4
	RRAP10		X	4.0	7.1
	RUSHYCK		X	2.0	2.1
Chapman Brook	CHAP12	X – restoration site		3.7	7.8
	CHAPX1	X – investigation site		12.2	57.1
Upper Chapman Brook	UCHAP1	X – control site		2.3	3.1
	UCHAPX2	X – restoration site		4.6	35.7
	UCHAP5	X – restoration site		7.4	36.0
	UCHAP6	X – control site		5.3	19.1
Fisher Creek	FISHX3	X – control site		13.2	33.8
Blackwood River	BLA15 BLA16	X – investigation site X – investigation site		12.4	48.6
	BLA16X	X – investigation site		n/a	n/a

Note: site coordinates are available on request from Water Science Branch, Department of Water.

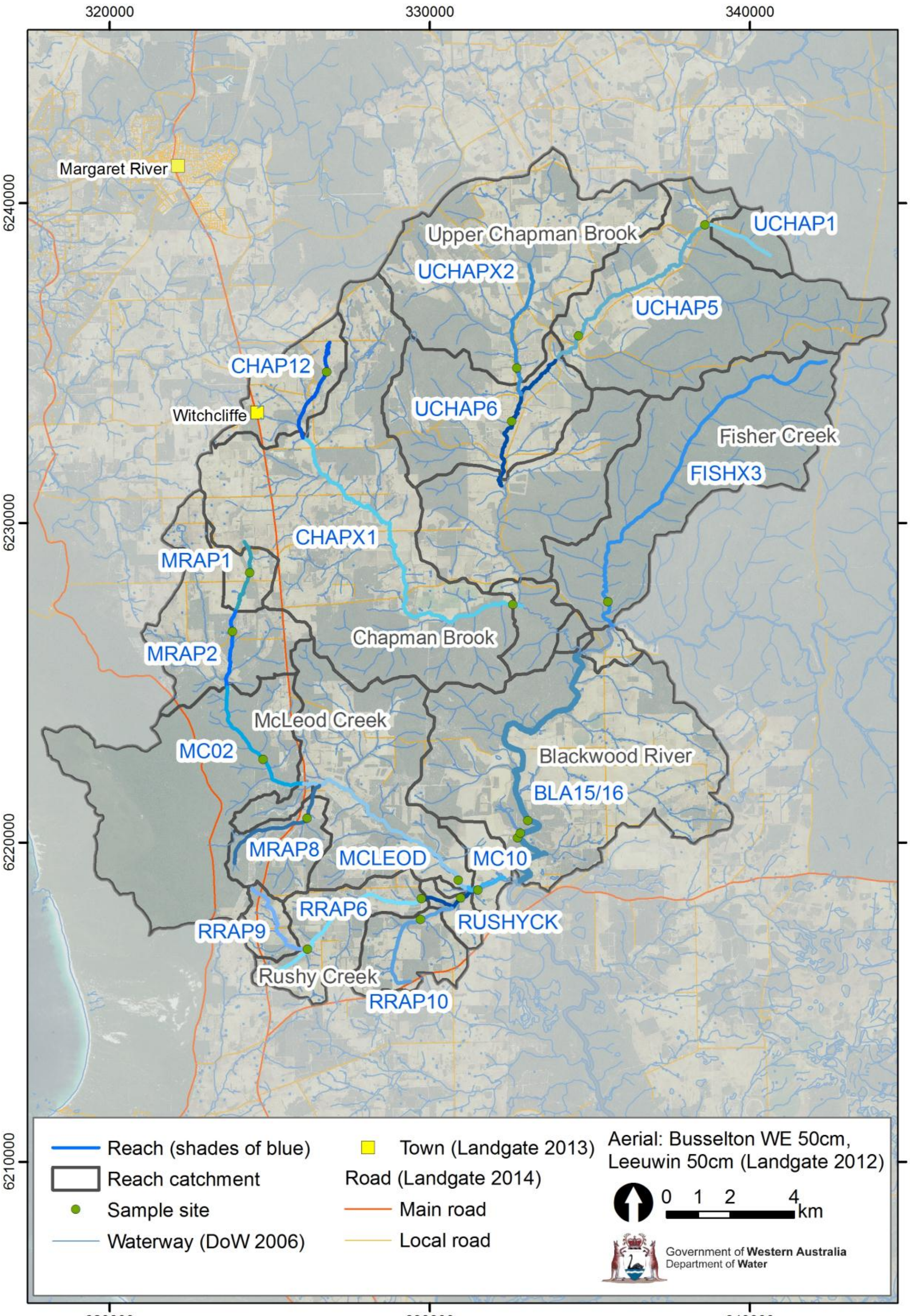


Figure 18 Site locations, reaches and catchments

3.3 Indicator selection and data collection schedule

For this study, all six themes of the SWIRC were selected for assessment, along with all sub-themes and components: this ensured a comprehensive assessment of river health was undertaken to meet the study's objectives.

Data collection was scheduled in three phases, assessing all themes in October 2012 (spring) and targeting specific sub-themes in June 2012 (winter) and February 2012 (summer), as follows:

June 2012 – selected sub-themes

The nitrogen, phosphorus, turbidity and salinity sub-themes of the water quality theme were assessed in June 2012 to measure the temporal variability in water quality. The specific analytes measured are detailed in Section 3.4.5. Supplementary water quality data were also collected (see Section 3.4.5).

Sampling for these sub-themes was targeted at the sites selected for objective one of the study and was conducted on 18 to 19 June 2012 (Table 5).

October 2012 – all themes

All SWIRC themes, sub-themes and components were assessed in spring 2012.

Desktop data collection began in September 2012. (Note: the spatial and hydrological datasets used in the assessment cover different temporal periods; details are provided in Section 3.4).

Field data for this assessment were collected between 8 and 25 October 2012, with one exception: field observations of fringing zone and physical form at sites BLA15 and BLA16 were made in February 2013, due to time constraints in October 2012.

Field and desktop data were collected at all study sites and reaches with the following exceptions (Table 5):

- aquatic biota were not sampled at the Blackwood River sites (BLA15, BLA16) as a representative sample could not be obtained using standard methods (and was not warranted) due to the relatively large channel size of the Blackwood River
- non-nutrient contaminants were assessed at four sites only (CHAP12, UCHAP1, UCHAP5 and UCHP6) (see Section 3.4.5)
- site BLA16X was not sampled in October 2012 (this site was added in February 2013, see next page).

In addition to the field data gathered for the SWIRC themes, sub-themes and components, a range of contextual field observations were made to support interpretation of theme-related data. Observations included aquatic habitat, flow rate, channel characteristics, erosion management, land use and vegetation adjacent to the riparian zone, and barriers to connectivity (see field sheets in Appendix D).

The field and desktop data collected for the full assessment were scored using the protocols in the SWIRC.

February 2013 – selected sub-themes and supplemental information

The water quality theme was assessed in February 2013 to measure the temporal variability in water quality. The specific analytes measured are detailed in Section 3.4.5. Supplementary data were also collected (see Section 3.4.5).

Sampling for the water quality theme was targeted at the sites selected for objective one of the study, and was conducted on 4 to 7 February 2013 (Table 5). One additional site, BLA16X, was added during the summer assessment (for a sub-set of water quality sub-themes only): this was an ad-hoc assessment of water flowing into the Blackwood River from a tributary located between sites BLA15 and BLA16.

The fish and crayfish sub-theme was assessed in February 2013 to measure seasonal variability in aquatic biota communities. Sampling for these sub-themes was also targeted at the sites selected for objective one of the study, and was conducted on 4 to 7 February 2013 (Table 5).

During the course of the field sampling conducted in February 2013 it became clear that flow had ceased at several study sites on the Chapman and Upper Chapman brooks and McLeod Creek. To understand the bio-connectivity and existence of possible permanent water refuges for aquatic biota in these systems, additional ad-hoc observations of water depth and flow were made at some sites and road crossing points (see Section 3.4.2). These observations are reported under the hydrological change theme. Note: this was not a comprehensive survey of potential permanent water refugia – such a survey is suggested in Section 7.

Table 5 Indicators selected and schedule for field and desktop data collection

Waterway	Site & reach code	Assessment for future evaluations (objective 1)	Assessment for RAP (objective 2)	Field data collection			Desktop data collection
				Winter: 18–19 Jun 2012	Spring: 8–25 Oct 2012	Summer: 4–7 Feb 2013	
McLeod Creek	MRAP1	–	x	–	AB, WQ, FZ, PF[a]	–	WQ, FZ, PF, CD, HC
	MRAP2	–	x	–	AB, WQ, FZ, PF	–	WQ, FZ, PF, CD, HC
	MC02	x	x	WQ[b]	AB, WQ, FZ, PF	WQ, AB[d]	WQ, FZ, PF, CD, HC
	MRAP8	–	x	–	AB, WQ, FZ, PF	–	WQ, FZ, PF, CD, HC
	MCLEOD	–	x	–	AB, WQ, FZ, PF	–	WQ, FZ, PF, CD, HC
	MC10	x	x	WQ[b]	AB, WQ, FZ, PF	WQ, AB[d]	WQ, FZ, PF, CD, HC
Rushy Creek	RRAP9	–	x	–	AB, WQ, FZ, PF	–	WQ, FZ, PF, CD, HC
	RRAP6	–	x	–	AB, WQ, FZ, PF	–	WQ, FZ, PF, CD, HC
	RRAP10	–	x	–	AB, WQ, FZ, PF	–	WQ, FZ, PF, CD, HC
	RUSHYCK	–	x	–	AB, WQ, FZ, PF	–	WQ, FZ, PF, CD, HC
Chapman Brook	CHAP12	x	–	WQ[b]	AB, WQ[c], FZ, PF	WQ, AB[d]	WQ, FZ, PF, CD, HC
	CHAPX1	x	–	WQ[b]	AB, WQ, FZ, PF	WQ, AB[d]	WQ, FZ, PF, CD, HC
Upper Chapman Brook	UCHAP1	x	–	WQ[b]	AB, WQ[c], FZ, PF	WQ, AB[d]	WQ, FZ, PF, CD, HC
	UCHAPX2	x	–	WQ[b]	AB, WQ, FZ, PF	WQ, AB[d]	WQ, FZ, PF, CD, HC
	UCHAP5	x	–	WQ[b]	AB, WQ[c], FZ, PF	WQ, AB[d]	WQ, FZ, PF, CD, HC
	UCHAP6	x	–	WQ[b]	AB, WQ[c], FZ, PF	WQ, AB[d]	WQ, FZ, PF, CD, HC
Fisher Creek	FISHX3	x	–	WQ[b]	AB, WQ, FZ, PF	WQ, AB[d]	WQ, FZ, PF, CD
Blackwood River	BLA15	x	–	WQ[b]	WQ	WQ, FZ, PF	WQ, FZ, PF, CD, HC
	BLA16	x	–	WQ[b]	WQ	WQ	
	BLA16X	x	–	–	–	WQ[b]	

Notes:

[a] AB = aquatic biota, WQ = water quality, FZ = fringing zone, PF = physical form, CD = catchment disturbance, HC = hydrological change.

[b] Nitrogen, phosphorus, turbidity, salinity sub-themes only; diel dissolved oxygen and diel temperature sub-themes not assessed.

[c] Non-nutrient contaminants sub-theme assessed.

[d] Fish and crayfish sub-theme only; macroinvertebrate sub-theme not assessed.

3.4 Data collection and analysis methods

Note: much of the information in this section is from Storer et al. (2011b); please refer to this document for a full description of the SWIRC, including the purpose of each theme, and the development of the themes, sub-themes and components. Detailed data collection and interpretation methods documents are in preparation (contact the Water Science Branch, Department of Water).

Data were collected according to the SWIRC protocols and analysed using methods appropriate to each theme and sub-theme (details provided in sections 3.4.1 to 3.4.6).

Scores for the SWIRC indices, sub-indices and components were generated using the field data collected in October 2012 and desktop data collection from September 2012 onwards. The scoring protocol follows a nested structure, with the component scores being integrated to calculate sub-index scores, which are integrated to form index scores (Figure 19). (Note: at present a SWIRC scoring protocol has not been developed for the farm dams and non-nutrient contaminant sub-themes, see sections 3.4.2 and 3.4.5 respectively).

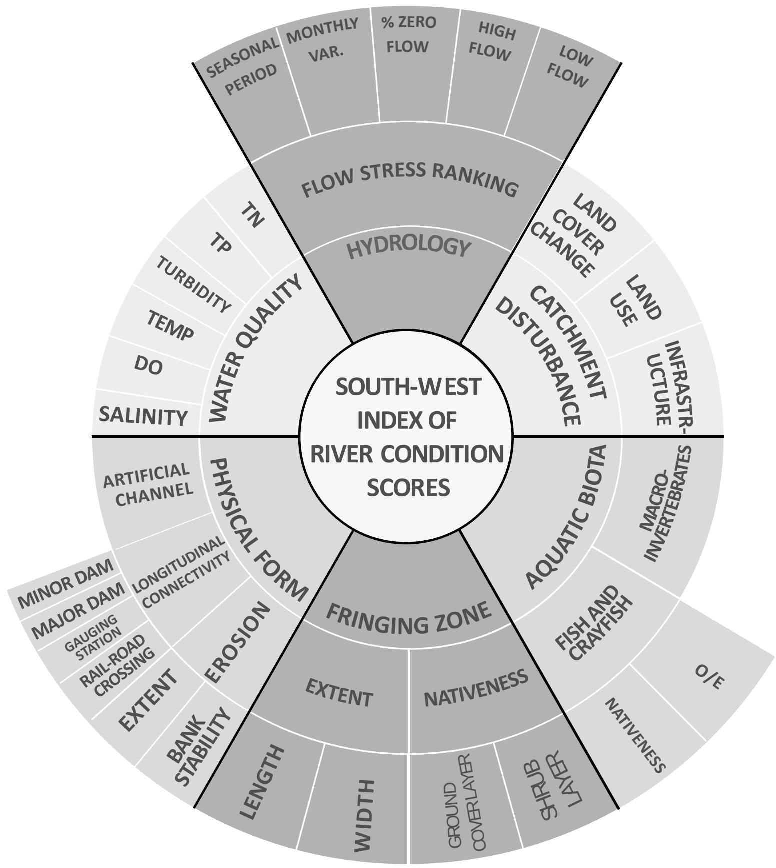


Figure 19 SWIRC score structure – indices, sub-indices and components

Note: this figure shows only indices and sub-indices (i.e. themes and sub-themes with a scoring protocol in place). It does not include the following sub-themes as they do not currently have scoring protocols: farm dams sub-theme (within the hydrological change theme) and non-nutrient contaminants sub-theme (within the water and sediment quality theme) – see Table 3 for the themes and sub-themes.

The scoring protocols are based on a reference condition approach. Each score provides a measure of the departure of the observed values from expected values. The expected values are those typically anticipated under minimal disturbance conditions, and can be derived from historical data, sample data from a minimally disturbed site or expert opinion (see Storer et al. 2011a for details).

Scores are divided into the condition bands represented in Table 6. The SWIRC scoring protocols facilitate comparability between river systems across Australia, in accordance with the principles of the national FARWH.

To place the scores in a regional context, the scores were compared with 236 reaches assessed between 2008 and 2009 across south-west Western Australia (data collected by Storer et al. 2011a, b).

Table 6 SWIRC scoring categories and condition bands (Storer et al. 2011a)

SWIRC score category	Condition band
0.8 – 1.0	Largely unmodified
0.6 – 0.79	Slightly modified
0.4 – 0.59	Moderately modified
0.2 – 0.39	Substantially modified
0 – 0.19	Severely modified

3.4.1 Theme: catchment disturbance

‘The physical characteristics of a catchment influence the river system via large-scale controls on hydrology, sediment delivery and chemistry (Allen & Johnson 1997). Consequently, disturbance within the catchment can affect the health of a river system (Boulton & Brock 1999; Allen 2004). For example, clearing the native vegetation from a catchment may lead to increased runoff and therefore higher flows, which can cause erosion of banks and sedimentation of channels and pools. It can also lead to increased groundwater recharge, potentially mobilising salt stored in the soil profile, resulting in the salinisation of land and river systems (Pen 1999). Other impacts of catchment disturbance include loss of riparian vegetation, eutrophication and contamination (e.g. herbicides, pesticides) (NWC 2007b)’ (Storer et al. 2011b).

‘The catchment disturbance theme is the primary pressure indicator of the SWIRC: it has a direct relationship with, or impacts on, all other themes. Assessing the amount of anthropogenic disturbance in a catchment provides information about causes of river health issues and highlights potential future impacts (NWC 2007a)’ (Storer et al. 2011b).

‘The catchment disturbance index comprises three sub-indices: land use, land cover change and infrastructure. These sub-indices characterise changes made to the land surface which can result in hydrological and riparian vegetation change, and increased runoff of sediments, nutrients and pollutants into rivers (i.e. large-scale diffuse source contaminants) (NWC 2007a,b)’ (Storer et al. 2011b).

Sub-theme: land use

'The land use sub-theme measures the chronic (long-term) impacts of land use on river health; for example, on-going effects from hydrological change, nutrient and sediment supply (dependent on actual land use) and supply of toxicants (NWC 2007b)' (Storer et al. 2011b).

The land use sub-theme was assessed using desktop-based analysis of spatial data at a catchment scale (the catchment of each reach) (Table 3).

Data collection

The source dataset used for this sub-theme was Blackwood Basin land use; this provides land use mapping for the study area based on interpretation of aerial photography from 2007 (Appendix Z).

The source dataset was merged with the reach catchment boundaries dataset, and the land use categories in the resulting dataset were amalgamated into broader categories defined by Storer et al. (2011b). The area of each land use type in each catchment was calculated.

Data analysis including scoring

Data were analysed descriptively, reporting the proportion of each land use type in each reach catchment.

Scores for the land use sub-index were calculated by multiplying the proportion of each land use present by a weighting that was derived from the ranking of impacts of land uses on river health (Table 7) – see Storer et al. (2011b) for details.

Table 7 Rankings and weighting for land use categories (Storer et al. 2011b)

	Impact factor ranking								
Land use	**Nutrients**	**Salinity**	**Biocides**	**Hydrological change**	**Sediment supply**	**Riparian change**	**Toxicants**	**Mean rank**	**Weight**
Urban	5	2	3	6	3	6	6	4.43	0.66
Intensive & irrigated agriculture	6	5	6	5	4	3	4	4.71	0.70
Dryland cropping	4	5	4	3	3	3	2	3.43	0.51
Grazing	2	4	3	1	2	3	1	2.29	0.34
Plantation forestry	1	2	3	2	1	1	1	1.57	0.23
Managed resources	1	1	–	1	1	–	–	0.57	0.08
Conservation	–	–	–	–	–	–	–	0	0

Sub-theme: infrastructure

'It is acknowledged that infrastructure is a form of land use, although it is not well delineated in land use datasets. Where it is included, there is little information about the type of infrastructure present. Consequently the variation in sediment, nutrient and toxicant exports from different infrastructure surfaces cannot be included in calculations. Given this particular land use comes into close proximity with rivers via crossing points and river corridors it is important to quantify the amount of infrastructure within a catchment separately to other land uses' (Storer et al. 2011b).

The infrastructure sub-theme was assessed using desktop-based analysis of spatial data at a catchment scale (the catchment of each reach) (Table 3).

Data collection

The source datasets used for this sub-theme were (see also Appendix Z):

- Road centrelines (dated September 2012)
- DPaW tracks and trails (dated September 2012)
- Railways (dated February 2010)
- Western Australian petroleum pipelines (dated October 2008).

The linear features in the source datasets were converted to polygon features using the typical width of each feature type as defined by Storer et al. (2011b). These features were merged with the reach catchment boundaries dataset, and the area of each infrastructure type in each catchment was calculated.

Data analysis including scoring

Data were analysed descriptively, reporting the proportion of each infrastructure type in each reach catchment.

Scores for the infrastructure sub-index were calculated by multiplying the proportion of each infrastructure type present by a weighting that was derived from the ranking of impacts of infrastructure types on river health (Table 8) – see Storer et al. (2011b) for details.

Table 8 Rankings and weighting for infrastructure categories (Storer et al. 2011b)

Infrastructure type	Impact factor ranking					Mean rank	Weight
	Nutrients	Agricultural biocides	Hydrological change	Sediment movement	Toxicants		
Main sealed road	3	1	6	3	6	3.8	0.7
Other sealed road	3	1	6	3	6	3.8	0.7
Railway	1	1	–	1	3	1.2	0.22
Unsealed road	4	–	2	6	1	2.6	0.48
Vehicle track	4	–	2	6	1	2.6	0.48
Utilities (power, pipes)	1	–	–	1	–	0.4	0.07
Walking track	–	–	–	–	–	0	0

Sub-theme: land cover change

'The land cover change indicator measures the acute (severe, short-term) impacts of vegetation clearing; for example, nutrient and sediment export resulting from the clearing process and step-change in runoff' (Storer et al. 2011b).

The land cover change sub-theme was assessed using desktop-based analysis of spatial data at a catchment scale (the catchment of each reach) (Table 3).

Data collection

The source datasets used for this sub-theme were the Land Monitor vegetation mask (south region) datasets for 2007 and 2011; these show the cover of perennial vegetation (Appendix Z).

The datasets were processed to calculate the area of vegetation loss in each reach catchment between 2007 and 2011 (five year period).

Data analysis including scoring

Data were analysed descriptively, reporting the proportion of vegetation loss in each reach catchment between 2007 and 2011.

Scores for the land cover change sub-index were calculated by multiplying the proportion of area of vegetation loss by a weighting of 0.68 – see Storer et al. (2011b) for details.

Calculation of the catchment disturbance index score

The sub-index scores were integrated to calculate the catchment disturbance index score using Equation 1.

Equation 1 $CDI = ISI + LCCSI + LUSI - 2$

Where: CDI = catchment disturbance index; ISI = infrastructure sub-index; LCCSI = land cover change sub-index; LUSI = land use sub-index.

Where Equation 1 returns a negative value, the catchment disturbance index score is rounded to zero.

'This integration approach (calculating the sum of the scores and scaling back to a score between 0 and 1) is used for indicators that quantify similar impacts on river health from different activities (NWC 2007a)' (Storer et al. 2011b).

3.4.2 Theme: hydrological change

'Flow regime is a key driver of river condition, being central to maintaining critical ecosystem elements, such as those related to connectivity and refugia; transporting nutrients and sediment; and controlling river geomorphology. Hydrological changes have been directly associated with anthropogenic impacts, such as land use changes and catchment activities' (Storer et al. 2011b).

The hydrological change theme comprises two sub-themes: flow stress ranking and farm dams. Supplemental data was also gathered about the presence or absence of flowing water on each sampling occasion.

Sub-theme: flow stress ranking

The flow stress ranking index determines the extent of hydrological change from unimpacted to current conditions by comparing elements of the flow time-series relating to each of these conditions. These elements are represented by five components: low flow, high flow, proportion of zero flow, monthly variation and seasonal period (SKM 2005).

The flow stress ranking procedure requires the comparison of two datasets: data showing the 'current condition' of the waterway being assessed, and data showing the 'reference condition'. It is recommended that each dataset has a total record of at least 15 years (NWC 2007b).

The flow stress ranking sub-theme was assessed using desktop-based analysis of hydrological data at a creek/brook catchment scale (Table 3).

Data collection

Note: there were insufficient historical flow data available for McLeod, Rushy and Fisher creeks and Upper Chapman Brook to calculate the flow stress ranking sub-theme. It was calculated for Chapman Brook only.

Flow data from 1996 to 2011 were obtained for Department of Water gauging stations on Chapman Brook (609023, Forest Grove) (Figure 6) and a tributary of Weld River (606002, Wattle Block), which flows into the Shannon River on the south coast of Western Australia (Figure 20). Data from the latter gauge were used to define reference condition; Weld River was chosen as a reference catchment because it receives a similar mean annual rainfall and is a similar sized catchment to Chapman Brook.

To standardise the two datasets, monthly flow volumes for each gauge were converted to monthly runoff (mm) by dividing the monthly flow (ML) by the catchment area (km^2).

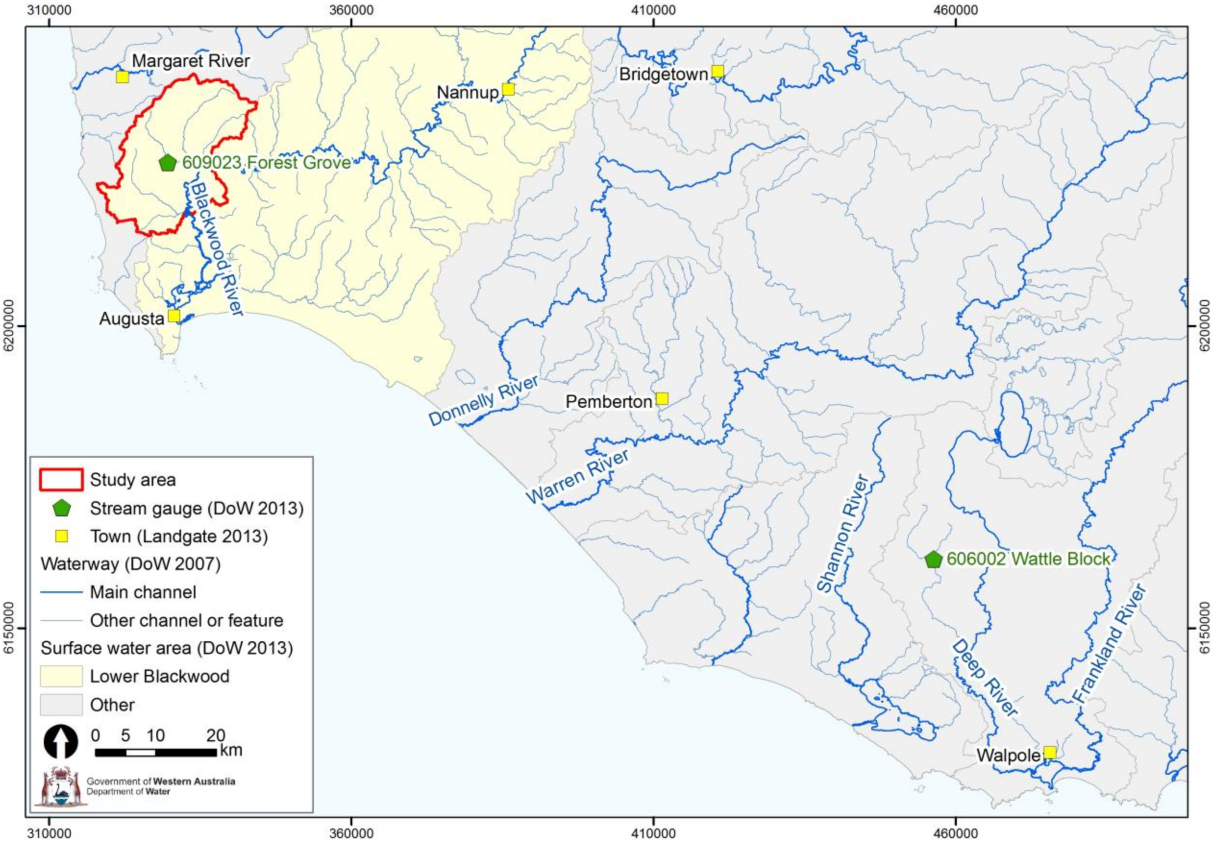


Figure 20 Location of stream flow gauging stations - data used to calculate the flow stress ranking

Data analysis including scoring

The data were used to calculate the five components of the flow stress ranking index:

- ‘The low flow (LF) component is a measure of the change in low flow magnitude under current and reference conditions. These were calculated based on the 91.7% exceedance flow (11 months out of 12) and the 83.3% exceedance flow (10 months out of 12).
- The high flow (HF) component is a measure of the change in high flow magnitude from reference to current conditions. The approach adopted to calculate the HF component was similar to that used to calculate the LF component. The monthly high flow was calculated based on the 8.3 and 16.7% exceedance flows (one and two months in 12 respectively).
- The proportion of zero flow (PZ) component compares the proportion of zero flow occurring under reference and current conditions. The value of the component varies from zero to one and, as with the other components, the direction of change was not evident from the score returned. If the number of cease-to-flow spells was unchanged between reference and current conditions, then the value of the component is one.

- The monthly variation (CV) component compares the coefficient of variation of monthly flows between current and reference conditions. The monthly variation score was calculated as the ratio of the variation of monthly flows under reference and current conditions, where the coefficient of variation was defined as the standard deviation divided by the mean.
- The seasonal period (SP) component compares the reference and current frequency distribution of maximum and minimum monthly flows. Frequency distributions were calculated that show the percentage of years that peak and minimum annual flows fall within each given month under current and reference conditions. The seasonal period score was then calculated by summing the minimum proportions (from reference or current) within each month' (Storer et al. 2011b).

Data were analysed descriptively, reporting the flow stress ranking component scores for each catchment.

The flow stress ranking index score was calculated by taking an unweighted average of the five component scores. Given the flow stress ranking index developed by SKM (2005) provides a score between 0 and 1, no further calculations are required to align the score with the SWIRC scoring structure (Storer et al. 2011b).

Calculation of hydrological change index score

The flow stress ranking sub-index score formed the hydrological change index score, with no further calculations required.

Sub-theme: farm dams

Note: a SWIRC scoring protocol for the farm dams sub-theme has not been developed to date, hence there is no farm dams sub-index in the SWIRC score structure diagram (Figure 19).

The farm dams sub-theme provides a measure of the impact of farm dams on flow within a catchment. It has two components:

- farm dam density – compares the water storage volume of farm dams with the mean area of the catchment; this gives an indication of the density of farm dams per catchment
- farm dam development – compares the water storage volume of farm dams with the mean annual flow volume of the catchment; this gives an indication of the proportion of flow that is being stored in farm dams.

The components were assessed using desktop-based analysis of hydrological and spatial data at a creek/brook catchment scale (Table 3).

Data collection

Note: Storer et al. (2011b) analysed the farm dam sub-theme at the reach scale, however for this study insufficient flow data were available at that scale, so the calculations were completed at a creek/brook scale (including the full length of Chapman and Upper Chapman brooks, which are excluded from reach-scale assessments, see Section 3.2).

The location and volume of farm dams in the creek/brook catchments were obtained from the farm dams dataset, produced in 2008 (Appendix Z). Where available, the volume for each farm dam was updated with information from the Department of Water's water resource licensing database.

The mean annual flow volume for each catchment was obtained from catchment modelling prepared for the Hardy Inlet WQIP Stage 2 (DoW in prep.).

The data were used to calculate the following (see Storer et al. 2011b for further information):

- the farm dam density component was calculated by dividing the total volume of farm dams in a catchment by the catchment area
- the farm dam development component was calculated by dividing the total volume of farm dams within a catchment by the mean annual flow of the catchment.

Data analysis

Data were analysed descriptively, reporting the farm dam density and development for each catchment.

To date a SWIRC scoring protocol for the farm dam data has not been developed, however this was proposed by Storer et al. (2011b) and may be developed in the future (contact Water Science Branch, Department of Water for further information).

Supplemental information

During the course of the field sampling conducted in February 2013 it became clear that flow had ceased at several study sites on the Chapman and Upper Chapman brooks and McLeod Creek. To understand the bio-connectivity and existence of possible permanent water refuges for aquatic biota in these systems, additional ad-hoc observations of water depth and flow were made at some sites and road crossing points (Table 9).

Table 9 Location, in addition to sample sites, where flow observations were made, February 2013

River	Site	Description	Coordinates (GDA94 MGA zone 50) Easting	Northing
McLeod Creek	Bussell Hwy	200 m north of Iles Rd	326107.01	6221826.86
Rushy Creek	Farm dam	Upstream of site RUSHYCK	330968.00	6218262.00
Chapman Brook	Rowe Rd	50 m from Mill Rd	326319.68	6233903.76
	Davis Rd	100 m from Rowe Rd	326352.52	6232337.39
	Chapman Pool	Campground at the confluence with Blackwood River	334499.40	6226140.67
Upper Chapman Brook	Chalice Bridge	Davis Rd 180 m west of Rosa Glen Rd	332846.37	6233797.21
	Rosa Glen Rd	800 m south of Bessell Rd	333897.85	6235035.42
	Noakes Rd	170 m west of Rosa Glen Rd	332247.07	6232059.77
	Warner Glen Rd	130 m west of Rosa Glen Rd	332818.28	6228166.30

3.4.3 Theme: fringing zone

'Fringing zone vegetation exists at the interface of aquatic and terrestrial environments, and the interactions between these two adjacent ecosystems contribute to the complexity of structure and processes within riparian zones (Naiman & Decamps 1997). Fringing vegetation also influences the adjoining landscapes. For example, riparian vegetation relies on periodic inundation from the river, and itself has an influence on the movement of water across the landscape (Rutherford et al. 2004)' (Storer et al. 2011b).

'Fringing vegetation can affect river health in a number of ways including provision of shading, food inputs, habitat, bank stability, filtering of overland flow. Given the strong reciprocal relationship between the health of fringing zone vegetation and both river health and level of catchment impact, it is a critical component of a river health assessment' (Storer et al. 2011b).

The fringing zone theme comprises two sub-themes: extent of fringing zone and nativeness.

Sub-theme: extent of fringing zone

The extent of fringing zone sub-theme provides a measure of the extent of fringing vegetation present along each reach. It comprises two components: fringing vegetation length and fringing vegetation width.

The components and sub-theme were assessed using desktop-based analysis of spatial data at a reach scale (Table 3).

Data collection

The source dataset used for both components was the Land Monitor vegetation mask (south region) 2011, which shows the cover of perennial vegetation (Appendix Z).

For the fringing vegetation length component, each study reach was clipped to the vegetation dataset and the length of perennial vegetation was calculated, expressed as a percentage of the total reach length. For further details see Storer et al. (2011b).

For the fringing vegetation width component, a series of transects were generated at 90º to the reach, extending 50 m from the reach line, spaced at 50 m intervals. Transects were clipped to the vegetation dataset, the width of transects adjacent to the reach were measured, and the average width of vegetation was calculated. For further details see Storer et al. (2011b).

Data analysis including scoring

Data were analysed descriptively, reporting the proportion of each reach covered by vegetation, and the average width of vegetation for each reach.

Scores for the fringing vegetation length component were calculated using Equation 2.

Equation 2 $FVLC = \frac{1}{100} \times percent\ of\ length\ vegetated$

Where: FVLC = fringing vegetation length component

Scores for the fringing vegetation width component were calculated using Equation 3.

Equation 3 $FVW = \frac{1}{50} \times \frac{(W_{T1} + W_{T2} + W_{T3} \ldots\ldots + W_{Tn})}{n}$

Where: FVW = fringing vegetation width component score; W_{T1} *= width of fringing zone in transect 1;* W_{T2} *= width of fringing zone in transect 2 and so on. n = total number of transects in the reach.*

Scores for the fringing zone extent sub-index score were calculated as the unweighted average of the two component scores for each reach.

Sub-theme: nativeness

The nativeness sub-theme provides a measure of the proportion of exotic species present at a site, which is a surrogate for the condition of the vegetation present (Storer et al. 2011b).

The sub-theme was assessed using field-based data at a site scale (Table 3).

Note: in Storer et al. (2011b) the nativeness sub-index scores was calculated using observations of the ground cover layer only. For this study, where on-ground works have focused on blackberry control and replanting, the sub-theme was expanded to include observations of nativeness in the shrub layer.

Data collection

The proportion of exotic species occurring within each vegetation layer was observed for the streamside zone (10 m from the waterline) on each bank of each site (defined as approximately 100 m in length). Observations were recorded in one of five categories (Appendix D).

The data were collected in October 2012 at all sites, except BLA15 which was assessed in February 2012. (Note: data were not collected at BLA16 as the vegetation observed was deemed to have very similar characteristics to that recorded at BLA15) (Table 5).

Data analysis including scoring

Data were analysed descriptively, reporting the proportion of exotic species in the ground cover and shrub layers.

To calculate the nativeness sub-index scores, the proportion of exotic species in the ground cover and shrub layers on each bank was assigned a condition score – for details see Storer et al. (2011b). The average score for the left and right banks for each layer was calculated. The nativeness sub-index score was calculated as the unweighted average of the ground cover and shrub layer scores.

Calculation of the fringing zone index score

The fringing zone index score was calculated as the unweighted average of the scores for the extent of fringing zone and nativeness sub-indices.

3.4.4 Theme: physical form

‘The purpose of the physical form theme is to ‘assess the state of local habitat and its likely ability to support aquatic life’ (NWC 2007a). Habitat is defined as the physical environment in which an organism or community usually occurs (WRC 2000; Pen 1999); for example, oligochaetes (segmented worms) are found in soft organically-rich sediments while philoreithrids (a family of stick caddisflies) occur among pebbles and rocks (Gooderham & Tsyrlin 2002). This is also important at a life-stage scale; for instance, spawning habitats of freshwater cobbler and western pygmy perch (endemic south-west Western Australian fish species) are sandy benthos and macrophytes respectively (Tim Storer pers. comm. 2010)’ (Storer et al. 2011b).

‘Due to the intrinsic link between an organism and its preferred environmental conditions, the availability, quality and diversity of habitats within a river system affect the characteristics of the biological community (Maddock 1999; Boulton & Brock 1999). Evaluating physical habitat is therefore an important component of any health assessment (Maddock 1999), and provides valuable information about pressures affecting the biota within a river system’ (Storer et al 2011b).

The physical form theme comprises three sub-themes: longitudinal connectivity, artificial channel and erosion.

Sub-theme: longitudinal connectivity

'The longitudinal connectivity sub-index provides a measure of the anthropogenic barriers to biota movement into and along each reach, which can be combined to evaluate the availability of the whole river system as habitat for fish and crayfish' (Storer et al. 2011b).

'Fish and crayfish move through river systems for a number of reasons including feeding, avoidance of predators, migration for breeding/spawning, migration to nursery areas or new territory, movement to seasonal habitats and colonisation (Storer & Norton, in prep). Anthropogenic and natural barriers can restrict these movements, leading to increased competition for food and microhabitats, increased predation and interruption of natural breeding/spawning cycles (Fairfull & Witheridge 2003). In addition, segregation of a population into localised groups can affect the genetic diversity of a group and its resilience to predation and environmental changes (Storer & Norton, in prep)' (Storer et al. 2011b).

'A number of anthropogenic structures exist within river systems that have the potential to prevent movement of fish/crayfish, including dams, weirs, flow gauging stations, fords and culverts. The extent to which a structure forms a barrier to fish/ crayfish passage depends on a combination of factors including the structure's size and the flow regime of the watercourse, which together determine how frequently the structure 'drowns out' the species present, their migration patterns and the location of the structures in relation to those patterns (NWC 2007b). In addition the barriers in neighbouring reaches can also affect fish/crayfish within a reach; expert advice suggests that species would be affected up to 20 km away from a barrier (NWC 2007b)' (Storer et al. 2011b).

Note: barriers to biota movement will also likely form barriers to the transport of sediment, nutrients and carbon through a river system.

The longitudinal connectivity sub-theme comprises four components: major dams, minor dams, gauging stations and road and rail crossings. The components and sub-theme were assessed using desktop-based analysis of spatial data at a reach scale (Table 3).

Data collection

The source dataset used for this study was the draft Stream barrier geodatabase created in 2009, which shows potential structures such as dams and road crossing occurring on waterways (Appendix Z). Note: the features in the geodatabase were generated from a series of spatial datasets. To date only a small proportion have been ground-truthed to confirm the presence of a structure and the extent to which it presents a barrier to biota movement, hence they are described as potential structures in this methods summary.

The potential structures within a 25 m distance of each reach were extracted from the geodatabase and were checked manually for any duplicate structures or structures located on tributaries. (Note: this is a departure from the method described by Storer et al. (2011b) who extracted potential structures within a 200 m width of each reach - this reflects the courser resolution of reach mapping used by Storer et al. (2011b) compared with the reaches in this study).

Potential structures were grouped into four component categories: major dams, minor dams, gauging stations and road/rail crossings. The total number of each type of structure occurring within 25 m of each reach was counted - this provides an indication of the likely ability of biota to move within the reach being assessed.

The total number of each type of potential structure occurring within 5 km, 20 km, 40 km and > 40 km of the ends of each reach was also counted (based on a manual comparison between the reaches and the geodatabase) - this provides an indication of the likely ability of biota to move into the reach being assessed.

Data analysis including scoring

Data were analysed descriptively, reporting the number of potential structures within and beyond each reach.

To calculate the component scores, the presence of structures within each reach, and upstream and downstream of each reach, were assigned a score (Table 10).

Table 10 Longitudinal connectivity sub-index scoring protocol (Storer et al. 2011b)

Major dam component	Minor dam component	Gauging station component	Road and rail crossing component	Score
Present on reach			Not applicable	0.00
Present within 5 km of start/end of reach			≥ 2/km (high density)	0.25
Present between 5 and 20 km of start/end of reach			1 – < 2/km (moderate density)	0.50
Present between 20 and 40 km of start/end of reach			> 0 – < 1/km (low density)	0.75
Present at > 40 km of start/end of reach			0/km	1.00

Scores for the longitudinal connectivity sub-index were calculated by applying a weighting to the component score for each reach. Weightings were assigned to components based on two factors: assumed potential for impact and confidence in source data (Figure 21). The greatest weighting was assigned to major dams, with reduced weightings assigned as confidence and potential for impact declined (Storer et al. 2011b).

The sum of the weighted component scores for each reach were range standardised to between 0 and 1 using Equation 4 – see Storer et al. (2011b) for details.

Equation 4 $$LCSI = \frac{((MiD \times w)+(MnD \times w)+(GS \times w)+(RR \times w)-(minimum\ possible\ score))}{(maximum\ possible\ score)-(minimum\ possible\ score)}$$

$$LCSI = \frac{((MiD \times w)+(MnD \times w)+(GS \times w)+(RR \times w)-0.06)}{2.50-0.06}$$

Where: LCSI = longitudinal connectivity sub-index; w = weighting; MjD = major dam component; MnD = minor dam component; GS = gauging station component, RR = road/rail crossing component.

Note: range standardisation process uses the theoretical minimum (in this case 0.06) and maximum (in this case 2.50) possible score (i.e.) calculated from theoretical scenarios.

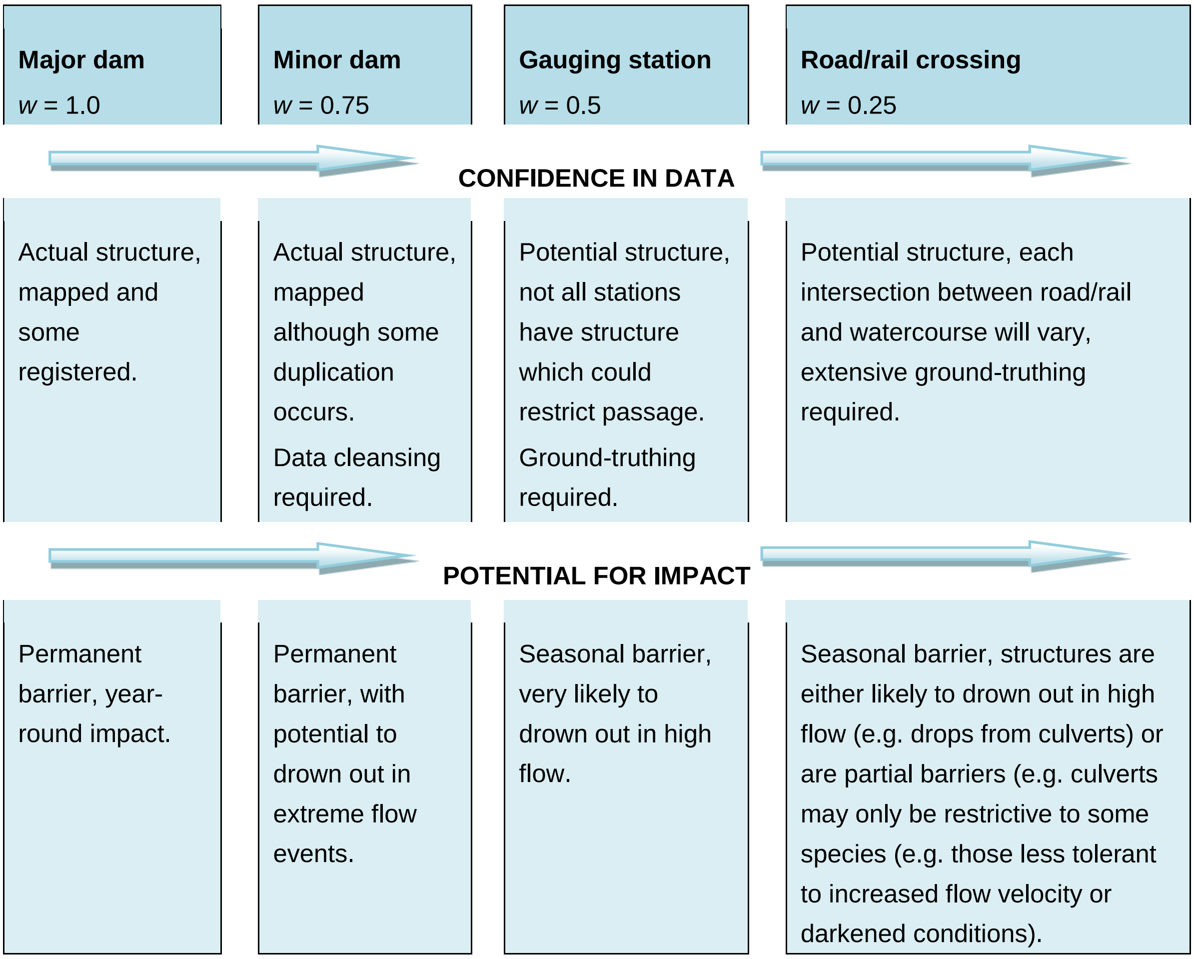


Figure 21 Potential for impact, confidence level and associated weightings for components of the longitudinal connectivity sub-index scoring protocol (Storer et al. 2011b)

Sub-theme: artificial channel

'The artificial channel sub-index was developed to provide an indication of the absence of macrohabitats within a reach. The presence of macrohabitats – such as riffles, pools and runs – are important to a river system's ecological health because they provide a diversity of environments for both plants and animals (Pen 1999). These morphological features are not currently mapped in south-west Western Australia, so it is not possible to assess the presence of these features without an extensive field survey, however a spatial dataset showing the location of artificial watercourses is available. This can be used as a proxy for the absence of features based on the observation that artificial watercourses (canals, drains etc.) are generally straight, have uniform width and depth, and therefore lack the characteristics of riffles, pools, meanders etc.' (Storer et al. 2011b).

The artificial channel sub-theme was assessed using desktop-based analysis of spatial data at a reach scale (Table 3).

Data collection

The source dataset used for this sub-theme was the hydrography theme of the GEODATA TOPO 250K Series 3, published in 2006 (Appendix Z).

The dataset was compared with the study reaches to determine the proportion of each reach mapped in the source dataset as either:

- watercourse line – a natural channel along which water may flow from time to time
- canal line – an artificial watercourse conveying water for inland navigation, irrigation or drainage purposes (GA 2006).

Data analysis including scoring

Data were analysed descriptively, reporting the proportion of each reach mapped as artificial channel (canal line).

Artificial channel sub-index scores were calculated based on the percentage of the reach length mapped as artificial channel (canal line) using Equation 5 - see Table 11 for examples of scores obtained (Storer et al. 2011b).

Equation 5 $ACSI = \frac{(\%\ length\ mapped\ as\ artifical\ channel - 100)}{(0-100)}$

Where: ACSI = artificial channel sub-index; AC = artificial channel.

Table 11 Examples of scores obtained using the artificial channel sub-index scoring protocol (Storer et al. 2011b)

Reach characteristics	Score
100% of reach length mapped as artificial watercourse	0.0
50% of reach length mapped as artificial watercourse	0.5
0% of reach length mapped as artificial watercourse	1.0

Sub-theme: erosion

The erosion sub-index provides a measure of current erosion and potential for future erosion (based on stabilising vegetation) occurring at a site, which is assumed to be representative of erosion along the reach in which the site is located. It was included in the SWIRC in recognition of the ecological impacts of geomorphological processes on aquatic microhabitats – see Storer et al. (2011b) for details.

The erosion sub-theme has two components: erosion extent and bank stabilisation. The components and sub-theme were assessed using field-based data at a site scale (Table 3).

Data collection

The extent of erosion features (e.g. slumping, gullying, and undercutting) observed on each bank of a site (approximately 100 m in length) was recorded in one of four categories (Appendix D). Data were collected in October 2012 at all sites, except BLA15 which was assessed in February 2012. (Note: data were not collected at BLA16 as the erosion observed was deemed to have very similar characteristics to that recorded at BLA15) (Table 5).

The percentage cover for each vegetation layer (shrubs, trees < 10 m tall, trees > 10 m tall) in the streamside zone (within 10 m of the waterline) on each bank of a site was recorded in one of five categories (Appendix D). The data were collected in October 2012 at all sites, except BLA15 which was assessed in February 2012. (Note: data were not collected at BLA16 as the vegetation observed was deemed to have very similar characteristics to that recorded at BLA15) (Table 5).

Data analysis including scoring

Data were analysed descriptively, reporting the proportion of each site length affected by erosion, and the percentage cover provided by each vegetation layer.

To calculate the erosion extent component scores, each extent category was assigned a nominal rating (Table 12). The rating for the left and right banks was averaged and range standardised (to between 0 and 1) using Equation 6 (Storer et al. 2011b).

Table 12 Erosion extent ratings (Storer et al. 2011b)

Extent of erosion (length of bank affected)	Rating
0 to 5%	4
> 5% to 20%	3
21 to 50%	2
> 50%	1

Equation 6 $$EES = \frac{\left(\frac{lbr+rbr}{2}\right) - min\ average\ rating\ possible}{(max\ average\ rating\ possible) - (min\ average\ rating\ possible)}$$

$$= \frac{\left(\frac{lbr+rbr}{2}\right) - 1}{4-1}$$

Where: EES = erosion extent score; lbr = left bank rating; rbr = right bank rating.

Note: the range standardisation process uses the theoretical minimum (in this case 1) and maximum (in this case 4) possible scores (i.e. calculated from theoretical scenarios).

To calculate the bank stabilisation component scores, each extent category was assigned a nominal rating (Table 13). The ratings for all three layers for both left and right banks were added together (using an unweighted sum) and the total rating was range standardised (to between 0 and 1) using Equation 7 (Storer et al. 2011b).

Table 13 Bank stabilisation ratings (Storer et al. 2011b)

% cover of vegetation (shrub layer, tree layer < 10 m, tree layer > 10 m)	Rating
> 75%	4
> 50 to 75%	3
> 10 to 50%	2
1 to 10%	1
0%	0

Equation 7 $$BSS = \frac{(LBS+LBTi+LBTii+RBS+RBTi+RBTii)-(min\ total\ rating\ possible)}{(max\ total\ rating\ possible)-(min\ total\ rating\ possible)}$$

$$= \frac{(LBS+LBTi+LBTii+RBS+RBTi+RBTii)-0}{24-0}$$

Where: BSS = bank stabilisation score; LBS = left bank shrub rating; LBTi = left bank tree < 10 m rating; LBTii = left bank tree > 10 m rating; RBS = right bank shrub rating; RBTi = right bank tree < 10 m rating; RBTii = right bank tree > 10 m rating.

Note: the range standardisation process uses the theoretical minimum (in this case 0) and maximum (in this case 24) possible score (i.e. calculated from theoretical scenarios).

The erosion sub-index score was calculated as the unweighted average of the erosion extent component and bank stabilisation component scores.

Calculation of the physical form index score

The three sub-index scores (longitudinal connectivity, artificial channel and erosion*)* were integrated into the overall physical form index score using the standardised Euclidean distance as recommended in the FARWH (NWC 2007b) (Equation 8) (Storer et al. 2011b).

This integration technique is recommended for use where the sub-indicators measure different aspects of physical form, which are then brought together to estimate overall status (NWC 2007a).

Equation 8 $$PFI = 1 - \frac{\sqrt{(1-LCSI)^2+(1-ACSI)^2+(1-ESI)^2}}{\sqrt{3}}$$

Where: PFI = physical form index; LCSI = longitudinal connectivity sub-index; ACSI = artificial channel sub-index; ESI = erosion sub-index.

3.4.5 Theme: water and sediment quality

‘Water quality encompasses a range of chemical and physical attributes that are important aspects of riverine habitat character and are useful indicators of catchment and riverine transport and biochemical information processes’ (NWC 2007b).

‘Historically, water quality has been used as a surrogate for ecological health, reflecting its versatility in representing both pressure and response. However, in recent times it has become apparent that water quality alone is not enough to define health, especially due to factors such as the synergistic effects of multiple parameters and an inability to test for everything. Rather, it is primarily a diagnostic tool to infer causes of biological change or highlight impacts from catchment disturbance' (Storer et al. 2011b).

The water quality theme comprises six sub-themes: nitrogen, phosphorus, turbidity, salinity, diel dissolved oxygen, diel temperature and non-nutrient contaminants.

In addition to the data collected under the sub-themes, several other water quality parameters are measured – see Supplementary water quality data.

Note: given that water quality generally varies through time, caution should be applied when interpreting data from a single or minimal number of samples as this can only give a snapshot of the conditions at the time of sampling. Long-term monitoring is required to determine the seasonal variability in conditions at a site.

Sub-theme: nitrogen

'Nitrogen is a fundamental element of primary production and can be a limiting agent in south-west Western Australian systems. This is a particularly applicable indicator given that eutrophication is one of the more common problems occurring in the region, due to widespread agriculture and associated fertiliser application. The situation is exacerbated by extensive clearing of fringing zone vegetation (reducing buffering capacity) and because systems are poorly equipped to deal with high nutrient concentrations due to their oligotrophic evolution' (Storer et al. 2011b).

'It should be noted that elevated nitrogen concentrations in south-west systems do not appear to reach toxic levels, but given the association with primary productivity and the related impacts from unnatural levels of algal growth, nitrogen remains a valuable indicator. Further, analysis of nitrogen concentrations is important in elucidating linkages between stream impacts and adjacent land uses, and as such has been used in numerous environmental impact assessment studies throughout the world (see review in Mulholland et al. 2005)' (Storer et al. 2011b).

The nitrogen sub-theme was assessed using field-based data at a site scale (Table 3).

Data collection

Water samples were collected and stored in accordance with the methods described by Heald (2009a, b) on three sampling occasions: June 2012, October 2012 and February 2013 (Table 5).

Samples were analysed by the National Measurement Institute (NMI) laboratory, using standard methods described by Heald (2009b), for the following analytes:

- total nitrogen (TN) (mg/L)
- total oxidised nitrogen (NOx-N) (mg/L)
- nitrogen as ammonia/ammonium (NH_3/NH_4-N), (mg/L)
- dissolved organic nitrogen (DOrgN) (mg/L).

Quality control samples (field blank, field replicate and field duplicate) were taken in accordance with the methods described by Heald (2009a, c) at one site in February 2012.

Data analysis including scoring

Data were analysed descriptively, reporting total nitrogen concentrations compared with the default guideline trigger value for slightly disturbed lowland river ecosystems in south-west Australia of 1.2 mg/L (ANZECC & ARMCANZ 2000a).

Note: this guideline trigger value is indicative only and was developed as a default guideline for use in situations where more specific guidelines (i.e. those developed using biological effects data and locally derived data) are not available (ANZECC & ARMCANZ 2000a).

Scores for the total nitrogen sub-index were assigned using concentrations recorded at each site in October 2012, based on categories defined by Storer et al. (2011b) (Table 14).

Table 14 Total nitrogen sub-index categories and scores (Storer et al. 2011b)

TN concentration (mg/L)	Category	Score
< 0.75	low	1
0.75 – 1.2	moderate	0.8
> 1.2 – 2.0	high	0.6
> 2.0	very high	0.4

Sub-theme: phosphorus

‘In south-west Western Australian systems phosphorus concentrations have not been recorded at a level considered directly toxic to aquatic biota. However, due to the effect of nutrient releases from extensive agriculture (among other land uses) in systems that have evolved in nutrient-poor environments, the subsequent impacts of nutrients (e.g. due to phytoplankton proliferation) can be significant. As such, phosphorus is an important inclusion in a south-west river health assessment’ (Storer et al. 2011b).

The phosphorus sub-theme was assessed using field-based data at a site scale (Table 3).

Data collection

Water samples were collected and stored in accordance with the methods described by Heald (2009a, b) on three sampling occasions: June 2012, October 2012 and February 2013 (Table 5).

Samples were analysed by the NMI laboratory, using standard methods described by Heald (2009b), for the following analytes:

- total phosphorus (TP) (mg/L)
- soluble reactive phosphorus (SRP) (mg/L).

Quality control samples (field blank, field replicate and field duplicate) were taken in accordance with the methods described by Heald (2009a, c) at one site in February 2012.

Data analysis including scoring

Data were analysed descriptively, reporting total phosphorus concentrations compared with the default guideline trigger value for slightly disturbed lowland river ecosystems in south-west Australia of 0.065 mg/L (ANZECC & ARMCANZ 2000a).

Note: this guideline trigger value is indicative only and was developed as a default guideline for use in situations where more specific guidelines (i.e. those developed using biological effects data and locally derived data) are not available (ANZECC & ARMCANZ 2000a).

Scores for the total phosphorus sub-index were assigned using concentrations recorded at each site in October 2012, based on categories defined by Storer et al. (2011b) (Table 15).

Table 15 Total phosphorus sub-index categories and scores (Storer et al. 2011b)

TP concentration (mg/L)	Category	Score
< 0.02	low	1
0.02 – 0.08	moderate	0.8
> 0.08 – 0.2	high	0.6
> 0.2	very high	0.4

Sub-themes: turbidity (including total suspended solids)

'Turbidity, whether biotic or abiotic, provides an important link with primary productivity and community dynamics (e.g. predator/prey interactions) through its influence on light penetration. High levels of turbidity have the potential to smother benthic organisms and habitat, affect fish due to mechanical and abrasive effects on gills (reducing oxygen uptake) and alter the prey/food selection of aquatic biota due to impacts on cost/benefit ratios due to increased searching in poor visibility, and altered water temperature (Storer 2005). The additional impacts often associated with unnaturally high bioturbidity (algal blooms) are assessed within other indicators (e.g. dissolved oxygen)' (Storer et al. 2011b).

The turbidity sub-theme was assessed using field-based data at a site scale (Table 3).

Data collection

Water samples were collected and stored in accordance with the methods described by Heald (2009a, b) on three sampling occasions: June 2012, October 2012 and February 2013.

Samples were analysed by the NMI laboratory, using standard methods described by Heald (2009b), for the following analytes:

- turbidity (NTU)
- total suspended solids (TSS) (mg/L).

Quality control samples (field blank, field replicate and field duplicate) were taken in accordance with the methods described by Heald (2009a, c) at one site in February 2012.

Data analysis including scoring

Data were analysed descriptively, reporting turbidity concentrations compared with the default guideline trigger value for slightly disturbed lowland river ecosystems in south-west Australia of 10 to 20 NTU (ANZECC & ARMCANZ 2000a).

Note: this guideline trigger value is indicative only and was developed as a default guideline for use in situations where more specific guidelines (i.e. those developed using biological effects data and locally derived data) are not available (ANZECC & ARMCANZ 2000a).

Total suspended solids data were compared with the Department of Water interim guideline trigger value of 6 mg/L (DoW unpublished data).

Scores for the turbidity sub-index were assigned using concentrations recorded at each site in October 2012, based on categories defined by Storer et al. (2011b) (Table 16).

Table 16 Turbidity sub-index categories and scores (Storer et al. 2011b)

Turbidity (NTU)	Category	Score
< 5	low	1
5 – 10	moderate	0.8
> 10 – 25	high	0.6
> 25	very high	0.4

Sub-theme: diel dissolved oxygen

‘Dissolved oxygen affects aquatic biota directly through oxygen availability for respiration, and indirectly through biochemical processes (Bott 2006; ANZECC & ARMCANZ 2000a). Oxygen levels outside of tolerance ranges can have both acute (e.g. mortality) and chronic (e.g. growth) effects, depending on extent and duration. Low oxygen levels can also increase the release of nutrients and some metals from sediments, in turn influencing stream health’ (Storer et al. 2011b).

The diel dissolved oxygen sub-theme was assessed using field-based data at a site scale (Table 3).

Data collection

Dissolved oxygen concentrations (mg/L) were recorded using YSI[2] 5739 probes connected to TPS WP-82Y meters, following the method described by Galvin et al. (2009) (Figure 22). Two probes were installed to allow for limited replication and backup in case of equipment failure. Data were recorded at 10-minute intervals over a 24-hour period on two sampling

[2] YSI and TPS are brands of equipment.

occasions: October 2012 and February 2013 (Table 5). Contextual observations about the habitat surrounding the probes were made (Appendix D) and the rate of flow passing the probes was measured using a Global Water flow meter.

Figure 22 Oxygen and temperature loggers installed in a waterway

Spot measurements of the dissolved oxygen concentration (mg/L) were also recorded using a Hydrolab Quanta multi-parameter water quality probe, in accordance with the methods described by Heald (2009a, b) on three sampling occasions: June 2012, October 2012 and February 2013 (Table 5).

Data analysis including scoring

Data were analysed descriptively, reporting dissolved oxygen concentrations compared with the biotic tolerance threshold described by Koehn & O'Connor (1990[3]) who suggest that, based on literature, concentrations below 5 mg/L may be stressful to many freshwater fish species. This threshold is supported by Waterwatch (2002), which suggests a concentration of 5 to 6 mg/L is required for fish growth and activity.

[3] The review of Victorian freshwater fish species by Koehn & O'Connor (1990) is cited in ANZECC & ARMCANZ (2000b) as background information for the development of the default guideline trigger value in ANZECC & ARMCANZ (2000a).

This threshold relates to stress rather than mortality in fish, thus it refers to long-term (chronic) conditions that may cause stress in fish, rather than short-term (acute) conditions that may cause death. Further, the threshold is a guideline only, and does not represent a definitive value at which all biota will become stressed. Each species is likely to respond differently to dissolved oxygen concentrations, and other factors such as temperature, competition and food availability may combine to create a stress response in biota.

Note: ANZECC & ARMCANZ (2000a) suggest a default guideline trigger value for slightly disturbed lowland river ecosystems in south-west Australia of 80% dissolved oxygen saturation (lower limit), however biological tolerances are expressed as a concentration rather than a saturation, and a saturation value (e.g. 80%) cannot be directly converted to a concentration (being a function of water temperature and salinity).

Scores for the diel dissolved oxygen sub-index were calculated using concentrations recorded at each site in October 2012, as follows (see Storer et al. 2011b for details):

- the length of time the dissolved oxygen concentration was in each of the six bands (Table 17) was calculated, and expressed as a proportion of the total 24-hour period
- if the concentration was below 2 mg/L for more than 25% of the 24-hour period, the data was assigned a score of zero
- if the concentration was not below 2 mg/L for more than 25% of the 24-hour period, the proportion of time within each condition band was multiplied by the weightings (Table 17), and the sum of the weighted proportions was calculated using Equation 9.

Table 17 Turbidity sub-index categories and scores (Storer et al. 2011b)

Band	DO concentration (mg/L)	Weighting
Band 1 (B_1)	> 6	1.0
Band 2 (B_2)	> 5 to 6	0.8
Band 3 (B_3)	> 4 to 5	0.6
Band 4 (B_4)	> 3 to 4	0.4
Band 5 (B_5)	2 to 3	0.2
Band 6 (B_6)	< 2	0.0

Equation 9 $$DO = (1.0 \times B_1) + (0.8 \times B_2) + (0.6 \times B_3) + (0.4 \times B_4) + (0.2 \times B_5) + (0 \times B_6)$$

Where: DO = the diel dissolved oxygen sub-index score for the site; B_1 = proportion of time spent in band 1; B_2 = proportion of time spent in band 2, and so on.

Sub-theme: diel temperature

'Water temperature has a strong relationship with both the structure and function of streams, influencing primary production, saturation of dissolved gases and metabolic rates of organisms (ANZECC & ARMCANZ 2000a; Rutherford et al. 2004; Bott 2006). Thermal stress in aquatic biota has been reported in all life stages, including growth, reproduction, mobility, survival and migration. In addition, temperature is a cue for many related events, such as emergence in macroinvertebrates, reproduction of lotic plants or onset of courtship behaviour and spawning in fish (e.g. Bott 2006). Temperature has also been linked with modification of chemical toxicity (ANZECC & ARMCANZ 2000a)' (Storer et al. 2011b).

'Temperature is a useful inclusion in river health assessment due to its ramifications for biotic health and direct relationship with a number of stressors. For example, a strong correlation exists between increasing temperature and loss of riparian vegetation (Smith et al. 2001). Temperature changes due to loss of riparian vegetation are particularly noticeable in smaller systems (characteristic of the south-west Western Australian landscape), with marked increases in both water temperature and range. Davies et al. (2004) reported a 10 °C increase in temperature in streams due to riparian clearing and a resultant reduction of oxygen concentration by 2.5 mg/L' (Storer et al. 2011b).

The diel temperature sub-theme was assessed using field-based data at a site scale (Table 3).

Data collection

Water temperature (°C) was recorded using YSI[4] 5739 probes connected to TPS WP-82Y meters, following the method described by Galvin et al. (2009). Two probes were installed to allow for limited replication and backup in case of equipment failure. Data were recorded at 10-minute intervals over a 24-hour period on two sampling occasions: October 2012 and February 2013 (Table 5). Contextual observations about the habitat surrounding the probes were made (Appendix D) and the rate of flow passing the probes was measured using a Global Water flow meter.

Spot measurements of the water temperature (°C) were also recorded using a Hydrolab Quanta multi-parameter water quality probe, in accordance with the methods described by Heald (2009a, b), on three sampling occasions: June 2012, October 2012 and February 2013 (Table 5).

Data analysis including scoring

Data were analysed descriptively, reporting the diel temperature range compared with the biotic tolerance threshold described by Storer et al. (2011b), based on a review of the literature, which suggest that a diurnal fluctuation of less than 4 °C is considered to be an indicative threshold for healthy ecosystem function.

Note: ANZECC & ARMCANZ (2000a) do not provide a default guideline trigger value for temperature, and instead recommend that system-specific low-risk trigger values are calculated using 80th and 20th percentiles of ecosystem temperature distribution. However, we do not have sufficient historical temperature data for these river systems with which to develop such a trigger value.

[4] YSI and TPS are brands of equipment.

The diel temperature sub-index scores were calculated using data recorded at each site in October 2012. The diel temperature range was calculated using the 95th and 5th percentile values (to reduce the effect of outliers) and scores were assigned based on categories defined by Storer et al. (2011b) (Table 18).

Table 18 Diel temperature sub-index categories and scores (Storer et al. 2011b)

Diurnal range	Score
< 4 °C	0.8
> 4 °C	0.4

Sub-theme: salinity

'Salinity is well-supported as an indicator of river health: it is easy to measure (low cost, accurate and rapid) and is a direct response measure of land use. Salinity can affect aquatic biota directly through specific tolerances (particularly due to effects on osmoregulation) and indirectly via the relationship with concentrations of other parameters (changing chemical equilibria and solubility of some minerals due to altered portions of anions and cations). Further, salinity can present a physical barrier to aquatic biota (Storer & Norton, in prep) and also to movement of oxygen from surface waters to benthos (Nielsen et al. 2003), with obvious secondary ramifications' (Storer et al. 2011b).

The salinity sub-theme was assessed using desktop-based analysis of spatial data at a reach scale (Table 3). Field-based data were also collected at a site scale to provide contextual data for the interpretation of aquatic biota data.

Data collection

The source dataset used for this sub-theme was the stream salinity status, published in 2005 as part of a study by Mayer et al. (2005) (Appendix Z). The dataset was compared with the study reaches to determine the salinity categories applying to each reach.

For contextual information, field-based spot measurements of the electrical conductivity (µS/cm, compensated to 25 °C) were recorded using a Hydrolab Quanta multi-parameter water quality probe, in accordance with the methods described by Heald (2009a, b), on three sampling occasions: June 2012, October 2012 and February 2013 (Table 5).

The data were converted to an estimated salinity concentration using Equation 10 (Hart et al. 1991; ANZECC 1992, cited in ANZECC & ARMCANZ 2000b) to allow comparison with guidelines.

Equation 10

$$Estimated\ salinity\ (TDS)(mg/L) = 0.68\ \times electrical\ conductivity\ (\mu S/cm)$$

This conversion factor provides an estimate of salinity only. It is possible to calculate salinity if the relationship between electrical conductivity and total dissolved salts has been empirically determined using samples from each river system, however such data do not exist for the study area and were beyond the scope of this study.

Data analysis including scoring

To calculate the salinity sub-index score for each reach, the stream salinity status dataset was compared with the study reaches to determine the salinity categories applying to each reach. The most commonly occurring (mode) category for each reach was selected, and the associated score was assigned to the reach (Table 19).

Table 19 Salinity sub-index categories and scores (Storer et al. 2011b)

Salinity (mg/L TDS)	Category (mapped) (Mayer et al. 2005)	Score	Biotic tolerances
< 500	Fresh	1	Low-level impact to macroinvertebrates
500–1000	Marginal	1	Low impact to macrophytes towards upper level
1000–1500	Marginal-brackish	0.9	Sensitive macroinvertebrates affected
1500–3000	High-brackish	0.8	Effects to fringing vegetation. Lethal effects to some species of micro/macroinvertebrates
3000–7000	Low-saline	0.5	Loss of species (algae, macrophytes, sensitive fish and micro/macroinvertebrates e.g. oligochaetes/gastropods)
7000–14 000	Mid-saline	0.2	Loss of less sensitive fish species
14 000–35 000	High-saline	0	Marron (particularly insensitive to salinity) are lost around 17 000 mg/L
> 35 000	Brine (seawater)	0	

Estimated salinity concentrations were analysed descriptively, reporting concentrations compared with the biotic tolerance threshold described by Hart et al. (1991) (also cited in ANZECC & ARMCANZ 2000b) who suggest that if salinity increased to 1000 mg/L in Australian river and wetland ecosystems, adverse biological effects were likely to occur. This threshold is a guideline only, and does not represent a definitive concentration at which all biota will become stressed; the tolerance of freshwater flora and fauna to electrical conductivity/salinity varies by species (see Storer et al. 2011b for a summary of the literature).

Note: the threshold suggested by Hart et al. (1991) is only applicable to freshwater systems. Given the reach of the Blackwood River in this study is within the limit of tidal influence (Hodgkin 1978), this threshold is not applicable to sites on this reach.

Note: ANZECC & ARMCANZ (2000a) provide a guideline default trigger value for conductivity for slightly disturbed lowland and river ecosystems in south-west Australia of 120 to 300 µS/cm electrical conductivity. This is substantially lower than the threshold suggested by Hart et al. (1991) and is described in ANZECC & ARMCANZ (2000b) as relating to ‘substantially natural and slightly disturbed ecosystems’, hence it was not used in this report.

Sub-theme: non-nutrient contaminants

Note: a SWIRC scoring protocol for the non-nutrient contaminants sub-theme has not been developed to date, hence there is no non-nutrient contaminants sub-index in the SWIRC score structure diagram (Figure 19).

For this study, a broad range of water and sediment contaminants were assessed including metals, herbicides and pesticides. The contaminant suite was derived through consultation with the SWCC, considering land use practices within the study area.

Herbicides were targeted in the water sample because these compounds are water soluble and more likely to exist in the water fraction. Metals and pesticides were targeted in sediment as sediments are a common site of accumulation of these contaminants and thus provide an indication of chronic exposure. Particle size analysis was conducted to determine the particle size distribution of the sediments, which relates to the potential contaminant-binding capacity.

The non-nutrient contaminant sub-theme was assessed using field-based data at a site scale (Table 3).

Note: assessment of non-nutrient contaminants was not included in the SWIRC methods summarised in Storer et al. (2011b).

Data collection

Four sites were chosen for water and sediment analysis, selected based on land use activities. Surficial sediments and surface water samples were collected at these sites in October 2012 (Table 5):

- one surface water sample was collected for the analysis of phenoxy acid herbicides and non-organochlorine and organophosphate herbicides
- one sediment sample was collected for analysis of bioavailable[5] metal concentrations and organochlorine and organophosphate pesticide concentrations
- one sediment sample was collected for the analysis of particle size distribution.

[5] Bioavailable metal concentrations are determined through a method that extracts only metals loosely bound to the surface of sediment particles, leaving behind those tightly bound in the mineral matrix (ANZECC & ARMCANZ 2000a). This is considered to provide an approximation of the metals that are biologically available.

Water chemistry

Water samples were collected and stored in accordance with the methods described by Heald (2009a, b).

Samples were analysed by the NMI laboratory, using methods accredited by the National Association of Testing Authorities (NATA) (Appendix E) for the analytes listed in Table 20. Contaminants were quantified to the lowest-available limit of reporting (Appendix E).

Quality control tests were conducted in the laboratory. A blank matrix test and a recovery from a blank reagent (method test) were conducted for each batch of samples, and a set of duplicate samples (randomly selected) was analysed in every 10 samples.

Table 20 Water contaminants assessed

Phenoxy acid herbicides		
Dicamba	2,4,5-T	Triclopyr
MCPA	2,4,5-TP	Picloram
Dichlorprop	2,4-DB	Clopyralid
2,4-D	MCPP	Fluroxypyr
Herbicides (non-organochlorine and non-organophosphate herbicides)		
Atrazine	Metolachlor	Prometryn
Diuron	Molinate	Simazine
Hexazinone	Oxyfluorfen	Trifluralin
Linuron	Pendimethalin	

Sediment chemistry

Whole-sediment (sediment and associated pore water) samples were collected in accordance with guidelines provided by Simpson et al. (2005) and the Environmental Protection Authority (EPA)(2005). Each sample, comprising 250 ml in volume, was a composite of the surficial sediment (approximately the top 2 cm, Simpson et al. 2005) from five cores collected within a 1 m by 1 m area. Samples were collected using a 95 mm diameter Perspex corer, and a portion of the top 2 cm of each core was transferred to the sample container (glass jar with Teflon lid) using a wooden spatula (the remainder was transferred to the particle size analysis container). Samples were stored on ice in the dark.

Samples were analysed by the NMI laboratory, using the methods accredited by NATA (Appendix E) for total organic carbon, moisture content and the analytes listed in Table 21. Before analysis, sediment chemistry samples were homogenised within a controlled laboratory environment according to method AS 4482.1-1997 (Standards Australia 1997). Contaminants were quantified to the lowest-available limit of reporting (Appendix E).

Quality control tests were conducted in the laboratory. A blank matrix test and a recovery from a blank reagent (method test) were conducted for each batch of samples, and a set of duplicate samples (randomly selected) was analysed in every 10 samples.

All quality assurance standards were met, confirming the integrity of the data.

Table 21 Sediment contaminants assessed

Bioavailable metals		
Aluminium	Copper	Mercury
Arsenic	Iron	Silver
Cadmium	Lead	Zinc
Chromium		
Organochlorine pesticides		
HCB	trans-Chlordane	Endrin Aldehyde
Heptachlor	cis-Chlordane	Endrin Ketone
Heptachlor epoxide	Oxychlordane	alpha endosulphan
Aldrin	Dieldrin	beta endosulphan
gamma-BHC (Lindane)	p,p'-DDE	Endosulphan sulphate
alpha-BHC	p,p'-DDD	Methoxychlor
beta-BHC	p,p'-DDT	
delta-BHC	Endrin	
Organophosphate pesticides		
Dichlorvos	Malathion (Maldison)	Parathion (Ethyl)
Demeton-S-Methyl	Fenthion	Parathion Methyl
Diazinon	Ethion	Pirimiphos Ethyl
Dimethoate	Fenitrothion	Pirimiphos Methyl
Chlorpyrifos	Chlorfenvinphos (E)	Azinphos Methyl
Chlorpyrifos Methyl	Chlorfenvinphos (Z)	Azinphos Ethyl

Sediment particle size

Whole-sediment samples were collected from the same five sediment cores taken for sediment chemistry analysis (see previous paragraphs). A portion of the top 2 cm of each core was transferred to the sample container (food-standard low-density polyethylene bag) using a wooden spatula. Samples were stored on ice in the dark.

Samples were analysed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Minerals, Western Australia laboratory, using the method given in Appendix E.

Data analysis

Data were analysed descriptively:

- Herbicide concentrations in water were compared with the ANZECC & ARMCANZ (2000a) trigger values for toxicants in fresh water for 95% species protection level. This level of protection applies to ecosystems classified as slightly to moderately disturbed.
- Metal concentrations in sediment were compared with the interim sediment quality guideline trigger values (ISQGs) from ANZECC & ARMCANZ (2000a). The low ISQG represents the concentration below which the frequency of adverse biological effects is expected to be low. The high ISQG represents the concentration above which adverse biological effects are expected to occur frequently.
- Pesticide concentrations in sediment were compared with ISQGs from ANZECC & ARMCANZ (2000a) where available. There are currently few ISQGs available for organochlorine pesticides, and none for organophosphate pesticides. Further, the ISQG low trigger values available are typically below the current laboratory reporting limits, therefore non-detect data should be treated with caution.
- Particle size data were described according to the Wentworth scale (Appendix E).

Note: at present the SWIRC does not include a scoring protocol for the non-nutrient contaminant sub-theme.

Supplementary water quality data

In addition to the parameters described under each sub-theme of the water quality theme, the following were measured to provide contextual data for interpreting aquatic biota data.

Data collection

Spot measurements of pH were recorded using a Hydrolab Quanta multi-parameter water quality probe on three sampling occasions: June 2012, October 2012 and February 2013 (Table 3).

Water samples were collected and stored in accordance with the methods described by Heald (2009a, b) on each sampling occasion, with the exception of alkalinity, which was only sampled in October 2012 to coincide with macroinvertebrate sampling.

Samples were analysed by the NMI laboratory, using standard methods described by Heald (2009b), for the following analytes:

- alkalinity ($CaCO_3$) (mg/L)
- dissolved organic carbon (DOC) (mg/L)
- colour (TCU).

Data analysis

Supplementary data were collected to provide contextual information – thus they have not been analysed for inclusion in this report’s Results section (see data in Appendix L).

Calculation of the water quality index score

To calculate the water quality index score, the six sub-indices were divided into ‘primary’ (salinity and dissolved oxygen) and ‘secondary’ (TN, TP, turbidity and temperature) indicators based on the impact they were likely to have on stream function (see Storer et al. 2011b for details).

The unweighted average of the four secondary sub-index scores was calculated. A precautionary approach was applied, where the worst score out of the three elements – two primary sub-indices (salinity and dissolved oxygen) and the average of the secondary sub-indices – was selected as the overall water quality index score (Equation 11).

Equation 11 $WQI = worst\ score\ of: (average\ of\ 2^{o} sub\ indices) or\ (salinity)\ or\ (diel\ DO)$

Where: WQI = water quality index score; average of 2^0 sub-indices is the average of the TN, TP, turbidity and temperature sub-index scores; salinity is the salinity sub-index score; and diel DO is the diel dissolved oxygen sub-index score.

3.4.6 Theme: aquatic biota

‘Aquatic biota is an important inclusion for river monitoring in south-west Western Australia. This is due to the ability of biota to reflect impact, as well as the region being recognised as one of the world’s 25 biodiversity hotspots, encompassing some of the richest and most threatened reservoirs of plant and animal life (Conservation International 2010)’ (Storer et al. 2011b).

‘Anthropogenic impacts and degradation of streams can affect the ability of an aquatic ecosystem to support natural diversity and maintain key ecological processes; damage to aquatic biota is often the end result of environmental degradation and pollution’ (Storer et al. 2011b).

‘Biological criteria are an important inclusion in any environmental health assessment because they directly measure the condition of water resources, detect problems that other methods may miss or underestimate, and also provide a systematic approach for measuring the progress of aquatic environment improvement programs (ITFM 1995)’ (Storer et al. 2011b).

The aquatic biota theme comprises two sub-themes: fish and crayfish and macroinvertebrates.

Sub-theme: macroinvertebrates

‘Macroinvertebrates are commonly used as indicators for assessing river health because they are widely distributed, relatively immobile and easily identified and sampled (Rosenberg & Resh 1993). In particular, macroinvertebrates are targeted for assessment as they are sensitive to environmental disturbance, with even small changes to the physical or chemical environment altering community composition and structure through the loss, addition or replacement of taxa. Macroinvertebrate community dynamics have been shown to reflect a number of anthropogenic activities including changes in water chemistry (Metzeling 1993), sedimentation (Doeg & Milledge 1991), land use (Kay et al. 2001), flow regime (Wood &

Petts 1994), salinity (Kay et al. 2001), heavy metal contamination (Grumiaux et al. 1998) and riparian vegetation loss (Quinn et al. 1997)' (Storer et al. 2011b).

The macroinvertebrate sub-theme was assessed using field-based data at a site scale (Table 3).

Data collection

Macroinvertebrate samples were collected and processed in accordance with the standard Australian River Assessment Scheme (AUSRIVAS) protocol described by van Looij (2009) on one sampling occasion: October 2012 (Table 5).

Channel habitat was selected as the habitat type to be sampled. A live-pick of 200 specimens from each sample was conducted in the field, using a box sub-sampler where necessary (Storer et al. 2011b). Microcrustaceans - Ostracods (seed shrimp), Copepods (copeopods) and Cladocerans (water fleas) - were excluded from the live-pick as per the AUSRIVAS protocol (van Looij 2009). (Note: Conchostracans (clam shrimp) and Anostracans (fairy shrimp, brine shrimp and sea monkeys) were included in the live-pick as per the protocol).

Macroinvertebrates were identified to species level where possible – the AUSRIVAS protocol requires macroinvertebrates to be identified to family level (with some exceptions, see below), however for this study, species level was selected to increase the pool of taxa available for data analysis. The exceptions to the species level identification were:

- Chironomids (non-biting midges) were identified to sub-family (van Looij 2009)
- Oligochaetes (segmented worms) and Acarinids (freshwater mites) were identified to order (van Looij 2009)
- Nematoda and Nemertea (unsegmented worms) were identified to phylum (not possible to identify to lower taxonomic levels),
- Temnocephalidea (unsegmented worms) were identified to family (not possible to identify to lower taxonomic levels).

Further, it is not always possible to complete the identification to the finest taxonomic resolution due to tissue destruction during sampling, sample deterioration before laboratory identification or the small size of some juveniles. Accordingly, there will commonly be a disparity between total abundance (which includes all animals) and relative abundance of the finest taxa levels. This disparity may also be seen in associated groupings (e.g. functional feeding groups). In this study, animals that could not be completely identified constituted 12% of total sample (at a site level this applied to a maximum of five taxa per site).

For sites where the box sub-sampler was used, the estimated abundance of each taxa was calculated using Equation 12. This applied to six of the 17 sites sampled (MRAP1, MRAP8, MC02, MCLEOD, RRAP9 and CHAP12).

Equation 12

$$Estimated\ abundance\ taxa\ A\ = \frac{total\ number\ of\ sub\ sampler\ cells}{cells\ picked \times number\ of\ taxa\ A\ individuals\ in\ sub\ sample}$$

Data analysis including scoring

Note: the macroinvertebrate results presented in this report are from a single sampling occasion in October 2012. As such, the results are a snapshot of the condition of the sites sampled and caution should be applied in extrapolating the data. A better understanding of the macroinvertebrate fauna in the lower catchment of the Blackwood River would be achieved by sampling for a number of years.

Data were analysed descriptively based on richness, abundance, community composition, and trophic structure (functional feeding groups). Functional feeding groups were assigned to taxa using literature including Hawking et al. (2009), Gooderham & Tsyrlin (2002) and Davis & Christidis (1997). Note: accurate information about the feeding preferences of many south-west taxa is unknown or poorly understood (WRM 2009), hence caution needs to be applied to the interpretation of this data.

To calculate the macroinvertebrate sub-index scores, the Western Australia spring channel AUSRIVAS model was used to generate an AUSRIVAS score and condition band. The model compared the macroinvertebrate family composition observed at a site against the composition predicted under unimpacted or reference conditions (expected). The expected macroinvertebrate assemblage was determined within the model from a set of minimally disturbed sites that have similar physical and geographical characteristics (predictor variables). The model used the following predictor variables to determine the probability of a site belonging to a set of reference site groups: latitude, longitude, mean annual rainfall, flow velocity at time of sampling and mean annual discharge (Storer et al. 2011b). The resultant observed/expected (O/E) score describes departure from reference condition.

AUSRIVAS scores range from 0 to > 1.15, split into condition bands (Table 22). The SWIRC macroinvertebrate sub-index scores were based on the AUSRIVAS scores generated. For AUSRIVAS scores of greater than one, the SWIRC score was calculated by subtracting the value greater than one from one – see Storer et al. 2011b for details.

Table 22 AUSRIVAS band thresholds and condition categories (Storer et al. 2011b)

Band	Band thresholds score	Condition
X	> 1.15	Enriched (slightly disturbed or biological hotspot)
A	0.85 – 1.15	Undisturbed
B	0.55 – 0.84	Significantly impaired
C	0.25 – 0.54	Severely impaired
D	0.00 – 0.24	Extremely impaired

Sub-theme: fish and crayfish

‘Fish (fish and crayfish) are a direct measure of biological organisation, which along with vigour and resilience, make up the three key attributes of a healthy ecosystem (Costanza 1992; Haskell et al. 1992). Fish provide an integrated measure of condition due to:

- direct sensitivity to water quality or general environmental change
- long-life (e.g. potential to highlight chronic or historical problems through changes in their population or community dynamics)
- mobility (e.g. representing wider system changes due to factors such as loss of connectivity or critical habitat destruction outside the immediate study area)
- position at the top of the food chain (reflecting a range of disturbances impacting on any level of the aquatic biological environment, including impacts that would not affect fish directly, such as changes to macroinvertebrate communities). This includes trophic impacts such as bioaccumulation (where low-level contaminants would otherwise go undetected)’ (Storer et al. 2011b).

‘Due to these attributes, certain responses of individual fish or the responses within population and community dynamics can be associated with specific environmental impacts; therefore fish have the potential to be a powerful indicator of health’ (Storer et al. 2011b).

The fish and crayfish sub-theme has two components: expectedness and nativeness, both of which were assessed using field-based data at a site scale (Table 3).

Data collection

Fish and crayfish samples were collected in accordance with protocol described by Storer et al. (2011b) (summarised briefly below) on two occasions: October 2012 and February 2013 (Table 5).

Note: a detailed guide to the SWIRC standard fish collection protocol is in preparation (contact Water Science Branch, Department of Water for further information).

Samples were collected using fyke nets (Figure 23) and box traps (Figure 24). The dimensions and deployment conditions are summarised in Table 23. Fyke nets and box traps were deployed for a 24-hour period.

Figure 23 Fyke net deployed in McLeod Creek (site MRAP02)

Figure 24 Box traps (large and small sizes)

Table 23 Nets and traps used for fish and crayfish sampling

Quantity and type	Dimensions	Deployment
Two dual-winged fyke nets[1]	• Opening (rectangular) 75 cm H x 105 cm W • Wings 55 cm H x 400 cm L • Mesh size 0.2 cm • Net 3 m long (hooped) • Opening (semi-circular) 55 cm H x 70 cm W • Wings 55 cm H x 400 cm L • Mesh size 0.2 cm • Net 3 m long (hooped)	One at each end of a 100 m section of river (study site), to capture species moving into the study site and to observe the direction of movement of individuals. Located in the centre of the stream with the wings extending to each bank to direct the animals in the mouth of the fyke. Ball float inserted in tail of fyke to enable surface access for air-breathing by-catch.
Five large box traps	• Opening (flexible mesh slit) length of short side • Box 21 cm H x 47 cm W x 60 cm L • Mesh size 2 cm	Baited with chicken pellets. Traps were placed between the two fyke nets.
Five small box traps	• Opening (circular) diameter 5 cm • Box 26 cm H x 26 cm W x 46 cm L • Mesh size 0.3 cm	Traps were placed to target all the in-stream habitat types present (e.g. bare bank, macrophytes, woody debris).

Notes:

[1] the type of fyke net used (rectangular or semi-circular opening) was selected based on the stream depth and width.

The following information was recorded for each sample:

- species
- abundance
- direction of movement (upstream or downstream – based on which fyke net fish were collected in)
- size class (see categories in Appendix F – note size classes have been calibrated to each species where the lowest size range relates to a juvenile of that species)
- visual signs of reproductive condition (including presence of berried or gravid females, nuptial colours, reddened vents, altered appearance of urogenital papillae)
- conspicuous signs of poor fish condition (presence of ectoparasites, disease, physical injury or behavioural symptoms of stress, such as moribund or lethargic individuals).

Data analysis including scoring

Data were analysed descriptively based on species richness, abundance, species distribution, temporal changes in composition and abundance, and population structure.

Scores for the expectedness and nativeness components were calculated using data collected in October 2012.

Expectedness component

The expectedness component considers the 'similarity in species composition of the observed native (non-exotic) assemblage of fish species to that predicted at a site under unimpacted or reference conditions (expected)' (Storer et al. 2011b).

The expectedness component comprises three metrics (Table 24).

A list of expected native species for each study site (Appendix G) was developed based on data from previous studies where available. (Note: due to a paucity of available data for much of the study area, the distribution of native species collected in this study was incorporated with expectations. Accordingly, interpretation of the expectedness component scores needs to be made with appropriate caution given the potential for Type I and Type II errors[6]; this is considered in the discussion).

The metric ratios were calculated for each site based on the species collected (observed) at each site compared with the species expected or predicted. The O/P_r and O/P_s metrics were integrated using Equation 13.

Equation 13 $$O/P = \left(\left((2 \times O/Pr) + O/Ps\right) \div 2\right) \div 1.5$$

Where: O/P = observed to predicted ratio; O/Pr = observed to predicted ratio: rare; O/Ps = observed to predicted ratio: seasonal.

Note: the O/Pr metric is given double the weighting of the O/Ps metric based on expert opinion; rare species were deemed more important as an indicator of system health than seasonal species (Storer et al. 2011b)

Note: the score was range standardised to between 0 and 1 by dividing the outcome of the bracketed equation by 1.5.

The resulting O/P ratio was integrated with the O/E ratio using an unweighted average to provide the expectedness component score.

[6] Type I errors occur then a correct hypothesis is rejected; type II errors occur when a false hypothesis is not rejected.

Table 24 Metrics of the expectedness components (Storer et al. 2011b)

Component	Metric	Definition	Contribution to sub-index score
Expectedness: species richness relative to reference condition	Observed to expected ratio (O/E)	Compares the native species expected to occur in a site based on reference condition and the actual species collected. The total number of native species predicted to occur in the subcatchment does not include species assigned as either rare or seasonal.	0.25
	Observed to predicted ratio: rare (O/P_r)	Compares the native species predicted to have occurred based on reference condition in a subcatchment against the native species actually caught at the site. This metric includes the rare species.	0.17
	Observed to predicted ratio: seasonal (O/P_s)	A comparison of the native species predicted to have occurred based on reference condition in a subcatchment against the native species actually caught at the site. This metric includes the seasonal species.	0.08

Nativeness component

The nativeness component provides a measure of the 'proportion of fish species and abundance that consist of native fish, as opposed to introduced or exotic fish' (Storer et al. 2011b).

The nativeness component comprises two metrics: proportion of native abundance and proportion of native species, which were calculated as described in Table 25.

Table 25 Metrics of the nativeness component (Storer et al. 2011b)

Component	Metric	Definition	Contribution to sub-index score
Nativeness: proportion of abundance and species richness that are native	Proportion native abundance	Proportion of individuals that are native species	0.25
	Proportion native species	Proportion of species that are native species	0.25
	Expert rule, exotic species cap: where exotic fish are present in the absence of natives the site is automatically assigned a score of 0.05. Where no fish are present the site is assigned a score of 0.		

The nativeness component score was calculated as the unweighted average of the proportion of native abundance and the proportion of native species. The exotic species cap expert rule was applied to sites where only exotic fish were collected, or no fish (native or exotic) were collected.

Calculation of fish and crayfish sub-index score

The fish and crayfish sub-index score for each site was calculated as an unweighted average of the expectedness and nativeness component scores.

Calculation of the aquatic biota index score

The aquatic biota index score was calculated by taking the unweighted average of the macroinvertebrate sub-index score and the fish and crayfish sub-index score.

3.4.7 Contextual observations

In addition to the field data gathered for the SWIRC themes, sub-themes and components, a range of contextual field observations were made to support interpretation of theme-related data.

Data collection

Field observations were made on a range of subjects including aquatic habitat, channel characteristics, erosion management, land use and vegetation adjacent to the riparian zone, and barriers to connectivity (see field sheets, Appendix D).

4 Results and SWIRC scores

4.1 Theme: catchment disturbance

This section reviews the three sub-themes of the catchment disturbance theme: land use, infrastructure and land cover change.

4.1.1 Sub-theme: land use

Land use within the study area (in 2007) was dominated by conservation/minimal use and grazing, with a small proportion being used for plantation forestry (primarily in the Rushy and McLeod creeks), intensive and irrigated agriculture, and urban/transport/mining activities (Figure 25; see also Figure 16).

Grazing constituted the greatest proportion of land use in all of the Rushy Creek reach catchments, while conservation/minimal use dominated the Upper Chapman Brook reach catchments. McLeod Creek and Chapman Brook reach catchments generally showed co-dominance between grazing and conservation/minimal use, with the exception of MC02, which was strongly dominated by conservation/minimal use, and MRAP1 and MC10, which were primarily grazing catchments.

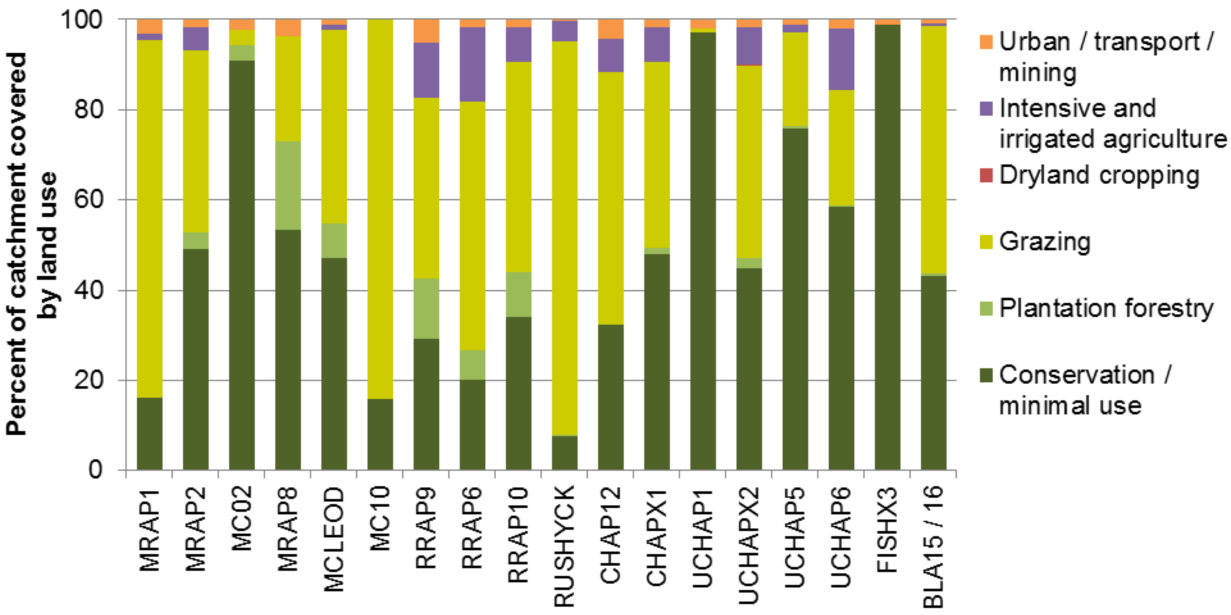


Figure 25 Land use within each reach catchment, 2007

4.1.2 Sub-theme: infrastructure

The proportion of each reach catchment covered by infrastructure was minimal, with a maximum of 1.6% of the catchment area for reaches MRAP1 and RRAP9 (McLeod and Rushy creeks), and a minimum of 0.3% in the MC10 and RUSHYCK reach catchments (Appendix J).

4.1.3 Sub-theme: land cover change

The land cover change between 2007 and 2011 was minimal, with most reach catchments having a loss or gain of perennial vegetation of less than 3% of the catchment area. The exception was reach MRAP8 in McLeod Creek, where the net vegetation loss equated to 11% of the catchment area (Figure 26). This vegetation clearing primarily occurred in areas of hardwood tree plantation in the central portion of the catchment.

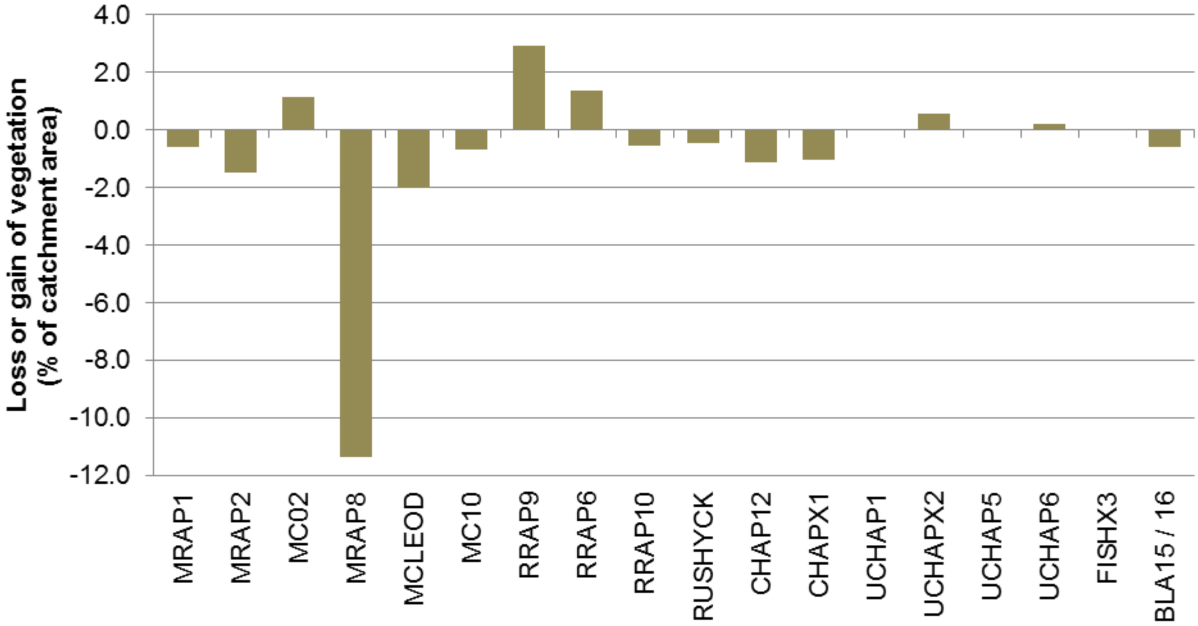


Figure 26 Net loss or gain of perennial vegetation within each reach catchment between 2007 and 2011

4.1.4 Scores: catchment disturbance index

The sub-index scores were as follows (Appendix H):

- the land use sub-index scores ranged from 0.67 to 0.99, placing all the reach catchments within the slightly modified or largely unmodified condition bands
- the infrastructure sub-index scores for all catchments was 1.0, placing all the reach catchments within the largely unmodified condition band
- the land cover sub-index scores ranged from 0.92 to 1.0, placing all the reach catchments within the largely unmodified condition band.

The catchment disturbance index ranged from 0.67 to 0.99 for all the reach catchments, placing them all within the slightly modified or largely unmodified condition bands (Figure 27).

The reach catchments dominated by national park or timber reserve (MC02, FISHX3 and UCHAP1) scored highest (1.0, largely unmodified), while those catchments with a higher proportion of agricultural and urban-type land uses had lower scores – reflecting the impacts of these land uses on river health.

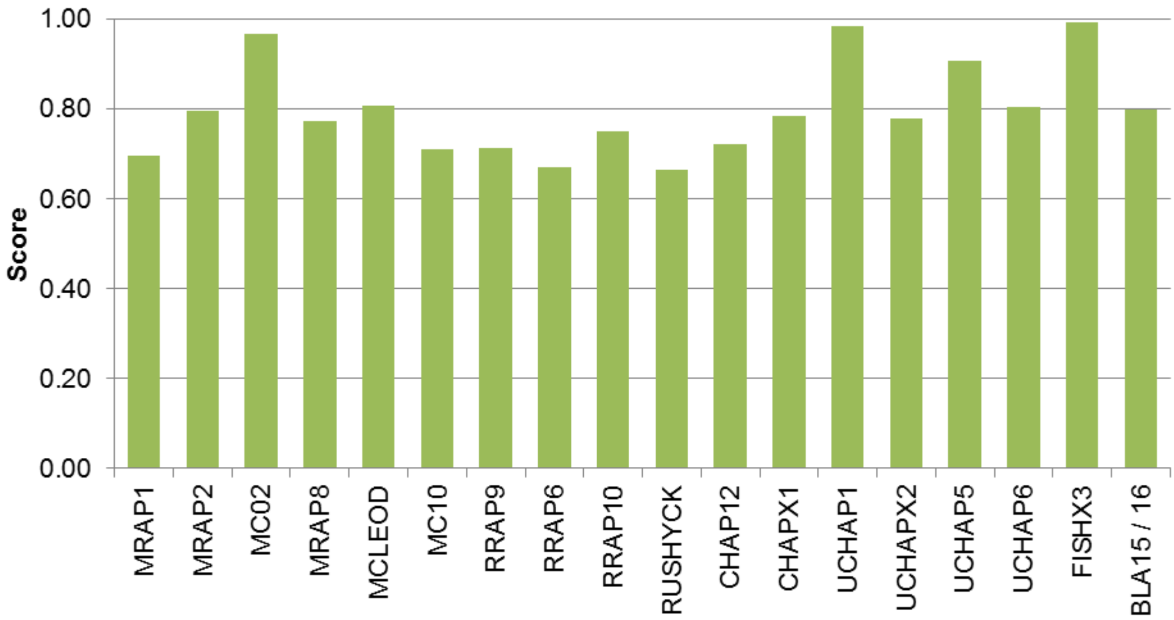


Figure 27 Catchment disturbance index score for each reach catchment

The catchment disturbance index scores for this study were compared with 234 reaches assessed between 2008 and 2009 across south-west Western Australia (Appendix I) (data collected by Storer et al. 2011a, b). The results show the study reaches were within the upper range of scores occurring across the south-west.

4.2 Theme: hydrological change

This section reviews the two sub-themes of the hydrological change theme: flow stress ranking and farm dam development, plus supplementary observations of flow conditions.

4.2.1 Sub-theme: flow stress ranking

The flow stress ranking was calculated for Chapman Brook only; flow data (gauged or modelled) for the other tributaries was of insufficient quality to complete the calculations.

The statistics calculated for the flow stress ranking for Chapman Brook are shown in Table 26. The low flow statistics indicate that Chapman Brook experiences a no flow period, with both the 91.7 and 83.3% exceedance flows at 0 mm/month. This is the same as those at the Weld River tributary, the reference catchment, which also experiences a no flow period. This indicates that the low flow part of the flow regime at Chapman Brook is behaving in a similar way to reference condition.

The high flow statistics indicate that Chapman Brook receives higher high flows than the Weld River tributary. The 8.3% exceedance flow refers to the flow that is exceeded 8.3% of the time. For Chapman Brook this was 79 mm, whereas for the Weld River tributary it was 29 mm.

The results also show that Chapman Brook has a smaller amount of zero flow months than the Weld River tributary.

Table 26 Flow stress ranking results for Chapman Brook and the reference gauge (a tributary of Weld River), 1996 to 2011

Component	Statistic	Chapman Brook (609023, Forest Grove)	Reference gauge (606002, Wattle Grove)
Low flow	91.7% exceedance flow	0 mm	0 mm
Low flow	83.3% exceedance flow	0 mm	0 mm
High flow	8.3% exceedance flow	79.3 mm	28.8 mm
High flow	16.7% exceedance flow	54.2 mm	18.5 mm
Proportion of zero flow	Percentage of months recording zero flow	22.4%	32.8%
Monthly variation	Monthly flow coefficient of variation	1.59 mm	1.79 mm

4.2.2 Sub-theme: farm dams

Farm dam density values varied throughout the study area (Table 27). Rushy Creek and Chapman Brook had the highest densities, at 39 and 24 ML/km^2 respectively. McLeod Creek and Upper Chapman Brook had lower densities, at 8 and 13.4 ML/km^2 respectively.

Farm dam development values were less than 15% throughout the study area (Table 27). Rushy Creek and Chapman Brook were the highest, with 15 and 10% of mean annual flow stored in farm dams respectively. McLeod Creek and Upper Chapman Brook had similar values between 4 and 7%.

Table 27 Farm dam density and development results, 2008

Catchment	Total volume of farm dams (ML)	Catchment area (km^2)	Mean annual flow (1992–2011, modelled) (GL)	Farm dam density (ML/km^2)	Farm dam development (volume as % of mean annual flow)
McLeod Creek	716	92	16.6	8	4.3
Rushy Creek	856	22	5.7	39	14.9
Chapman Brook	1555	65	15.0	24	10.4
Upper Chapman Brook	1166	117	23.5	13.4	6.6
Fisher Creek	0	34	4.6	0	0

4.2.3 Scores: hydrological change index

Flow stress ranking sub-index

The component scores for Chapman Brook ranged from 0.3 (high flow index) to 1.0 (low flow index), and the flow stress ranking score was 0.7 (Table 28).

Table 28 Flow stress ranking score and component scores for Chapman Brook, 2011

River	Low flow	High flow	Proportion of zero flow	Monthly variation	Seasonal period	Flow stress ranking
Chapman Brook (609023, Forest Grove)	1	0.3	0.8	0.9	0.7	0.7

Hydrological change index

The hydrological change index score is derived directly from the flow stress ranking sub-index score. Chapman Brook scored 0.7 and was therefore categorised as slightly modified (Table 29).

Table 29 Hydrological change index scores, 2011

Catchment	Flow stress ranking sub-index score	Hydrological change index score	SWIRC condition category
Chapman Brook	0.7	0.7	Slightly modified

4.2.4 Supplemental information

Observations of flow conditions at the sites on all sampling occasions, and at additional locations in February 2013, showed that the brooks and creeks were flowing in June and October 2012, with the exception of site UCHAPX1 on the Upper Chapman Brook in June 2012.

In February 2013, many of the locations visited were observed to be dry. Exceptions included the locations on the lower reaches of McLeod Creek (MC10) and Chapman Brook (Chapman Pool), close to the respective confluences with the Blackwood River. In addition, water was observed at site MRAP2 on the upper reaches of McLeod Creek, and UCHAPX2 and UCHAP5 on the Upper Chapman Brook (Table 30 and Figure 28).

Table 30 Observations of flow conditions (including estimated maximum water depth where available), 2012 to 2013

River	Site / location	June 2012	October 2012 (estimated max. depth in m)	February 2013 (estimated max. depth in m)
McLeod Creek	MRAP1	Wet – flowing	Wet – flowing (0.8 m)	No data
	MRAP2	Wet – flowing	Wet – flowing (0.6 m)	Wet – excavated pool at end of site (site dry)
	MC02	Wet – flowing	Wet – flowing (0.4 m)	Dry – completely
	Bussell Hwy	No data	No data	Dry – completely
	MRAP8	No data	Wet – flowing (0.7 m)	Dry – small puddle remaining d/s of crossing
	MCLEOD	Wet – flowing	Wet – flowing (1.2 m)	No data
	MC10	Wet – flowing	Wet – flowing (1–2 m)	Wet – flowing slowly (1.6 m)
Rushy Creek	RRAP9	No data	Wet – flowing (0.4 m)	No data
	RRAP6	No data	Wet – flowing (1 m)	No data
	RRAP10	No data	Wet – flowing (0.6 m)	No data
	RUSHYCK	Wet – flowing	Wet – flowing (0.8 m)	No data
	Farm dam	No data	Wet – flowing in spillway/bypass channel	Dry – no flow in spillway/bypass channel
Chapman Brook	CHAP12	Wet – flowing	Wet – flowing slowly (0.4 m)	Dry – completely
	Rowe Rd	No data	No data	Dry
	Davis Rd	No data	No data	Dry – small puddle remaining d/s of crossing
	CHAPX1	Wet – flowing	Wet – flowing (1.2 m)	Dry – small puddle remaining d/s of crossing
	Chapman Pool	No data	Wet – flowing	Wet – flowing (1.5 m)
Upper Chapman	UCHAP1	Dry – small puddle remaining	Wet – stationary (0.05 – 0.15 m)	Dry – completely

River	Site / location	June 2012	October 2012 (estimated max. depth in m)	February 2013 (estimated max. depth in m)
Brook	UCHAPX2	Wet – flowing	Wet – flowing (0.3–0.6 m, max 1 m)	Wet – flowing slowly (1 m)
	UCHAP5	Wet – flowing	Wet – flowing (0.3–0.5 m)	Wet – flowing slowly (0.4 m)
	Chalice Bridge	No data	No data	Dry – small puddles remaining at crossing
	Rosa Glen Rd	No data	No data	Dry – small puddle remaining d/s of crossing
	UCHAP6	Wet – flowing	Wet – flowing (max. 0.5 m)	Dry – completely
	Noakes Rd	No data	No data	Dry – small puddle visible
	Warner Glen Rd	No data	No data	Dry – completely
Fisher Creek	FISHX3	Wet – flowing slowly	Wet – flowing (0.1–0.3 m, max. 1 m)	Dry – completely
Blackwood River1	BLA15	Wet – flowing	Wet – flowing	Wet – flowing
	BLA16	Wet – flowing	Wet – flowing	Wet – flowing
	BLA16X	No data	No data	Wet – flowing

Notes: shading indicates wet, dry and no data

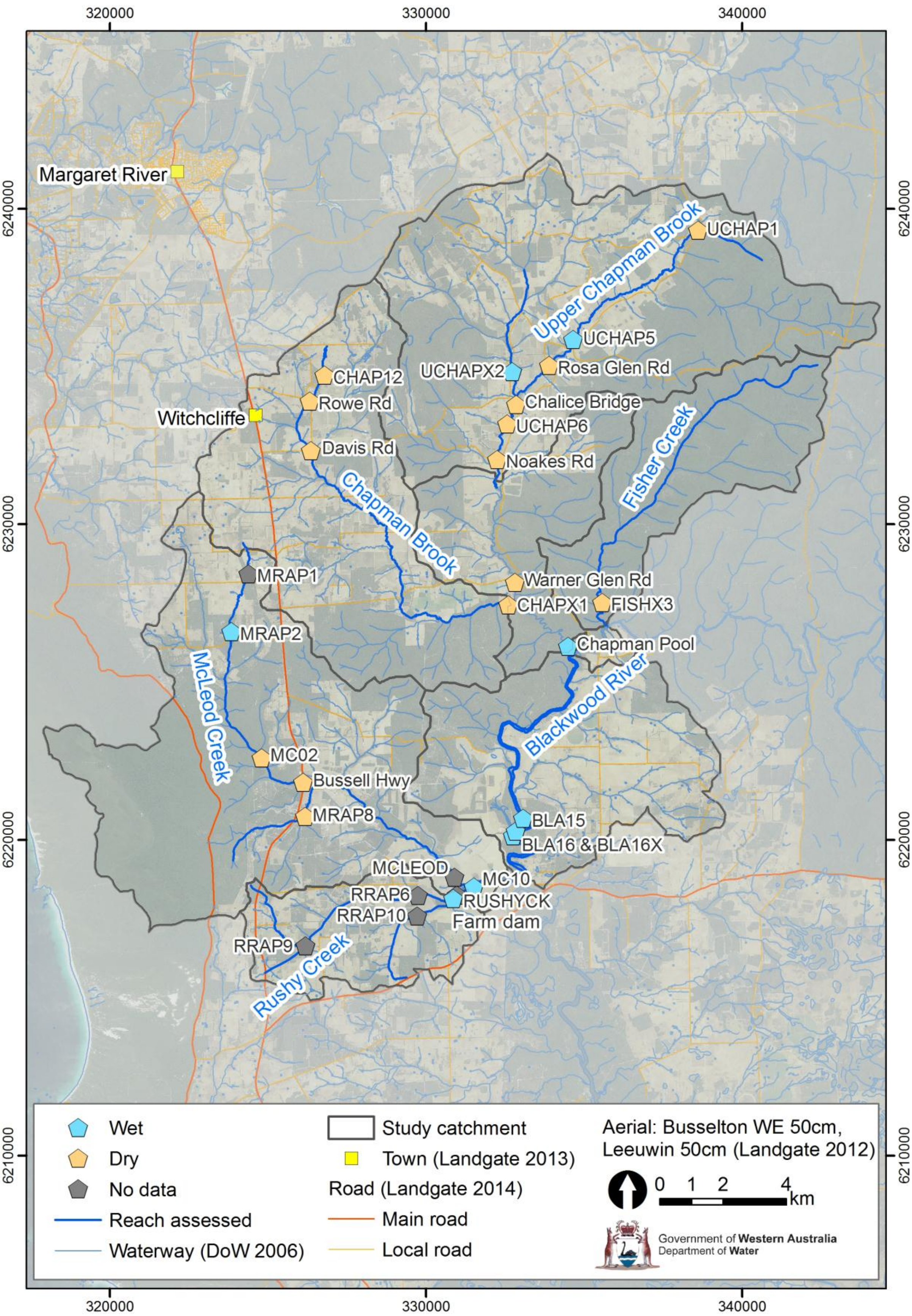


Figure 28 Flow conditions observed in February 2013

4.3 Theme: fringing zone

This section reviews the two sub-themes of the fringing zone theme: extent of fringing zone and nativeness.

4.3.1 Sub-theme: extent of fringing zone

The proportion of the length of each reach covered with vegetation ranged from 17 to 100% across all study reaches, while the average width of fringing vegetation (within the 50 m corridor assessed) ranged from 6 to 50 m (Figure 29). In general, a direct positive relationship was observed between the length and width of vegetation.

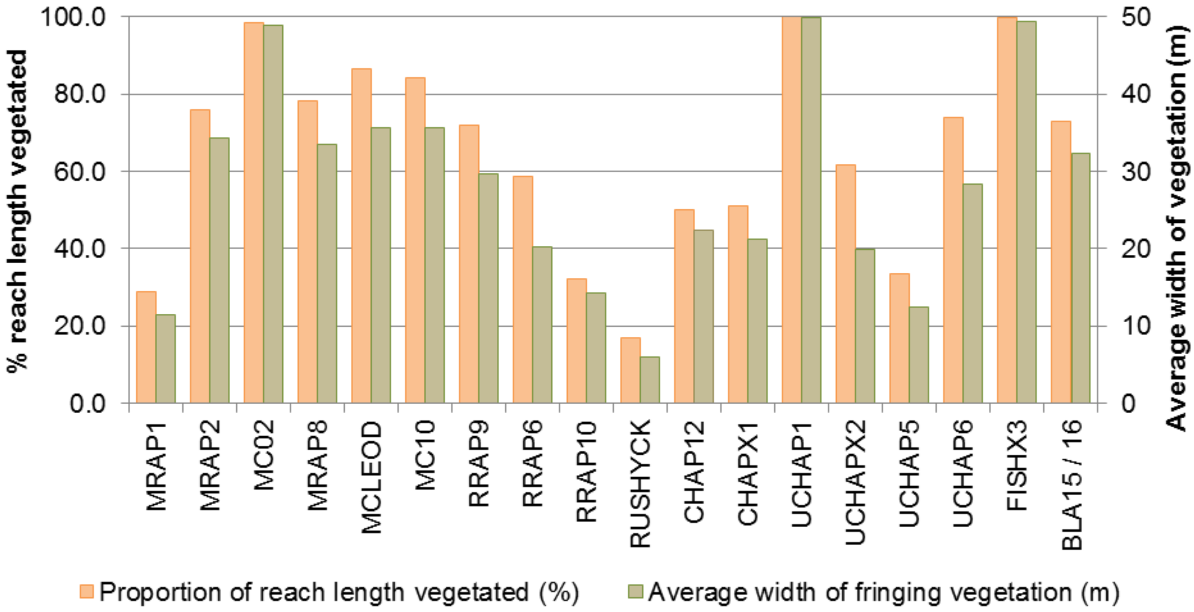


Figure 29 Extent of fringing vegetation (proportional length and average width) for each reach, 2011

4.3.2 Sub-theme: nativeness

Exotic plants were primarily found in the ground cover layer (Table 31); various exotic grasses were dominant, while arum lily (*Zantedeschia aethiopica*) was found at MRAP1 and RRAP9 and an exotic rush (*Juncas microephalius*) was found at MRAP8 and RUSHYCK. Exotic plants in the shrub layer were less common than the ground cover layer, with blackberry (*Rubus* sp.) at site RRAP9, and blackberry and thistles (species not identified) at CHAP12.

Table 31 Exotic vegetation in the ground cover and shrub layers at sites in October 2012

		Proportion of exotic vegetation			
		Ground cover layer (%)		Shrub layer (%)	
River	**Site**	**Left bank**	**Right bank**	**Left bank**	**Right bank**
McLeod Creek	MRAP1	>50–75	>50–75	0	0
	MRAP2	1–10	1–10	1–10	1–10
	MC02	1–10	1–10	0	1–10
	MRAP8	>10–50	>10–50	0	0
	MCLEOD	1–10	1–10	0	0
	MC10	0	0	0	0
Rushy Creek	RRAP9	>75–100	>75–100	0	1–10
	RRAP6	>10–50	>50–75	1–10	1–10
	RRAP10	0	1–10	0	0
	RUSHYCK	>75–100	>75–100	0	0
Chapman Brook	CHAP12	1–10	1–10	>10–50	>10–50
	CHAPX1	0	0	0	0
Upper Chapman Brook	UCHAP1	0	1–10	0	0
	UCHAPX2	>75–100	>75–100	1–10	1–10
	UCHAP5	>50–75	>50–75	0	0
	UCHAP6	>75–100	>50–75	0	0
Fisher Creek	FISHX3	0	0	0	0
Blackwood River[a]	BLA15/16	0	0	0	0

[a] *BLA 15/16 was assessed in February 2013.*

4.3.3 Scores: fringing zone index

Extent of fringing zone sub-index

The scores for the fringing zone extent ranged between 0.15 and 1.0, with most reaches scoring in the slightly modified condition band (0.6–0.79) (Figure 30). This spread of scores is consistent with the fringing vegetation length and fringing vegetation width component scores (Appendix H).

The highest fringing zone extent sub-index scores occurred on reaches within national parks and timber estates (FISHX3, UCHAP1 and MC02). The lowest scores occurred on reaches in McLeod Creek (MRAP1), Rushy Creek (RUSHYCK and RRAP10) and Upper Chapman Brook (UCHAP5).

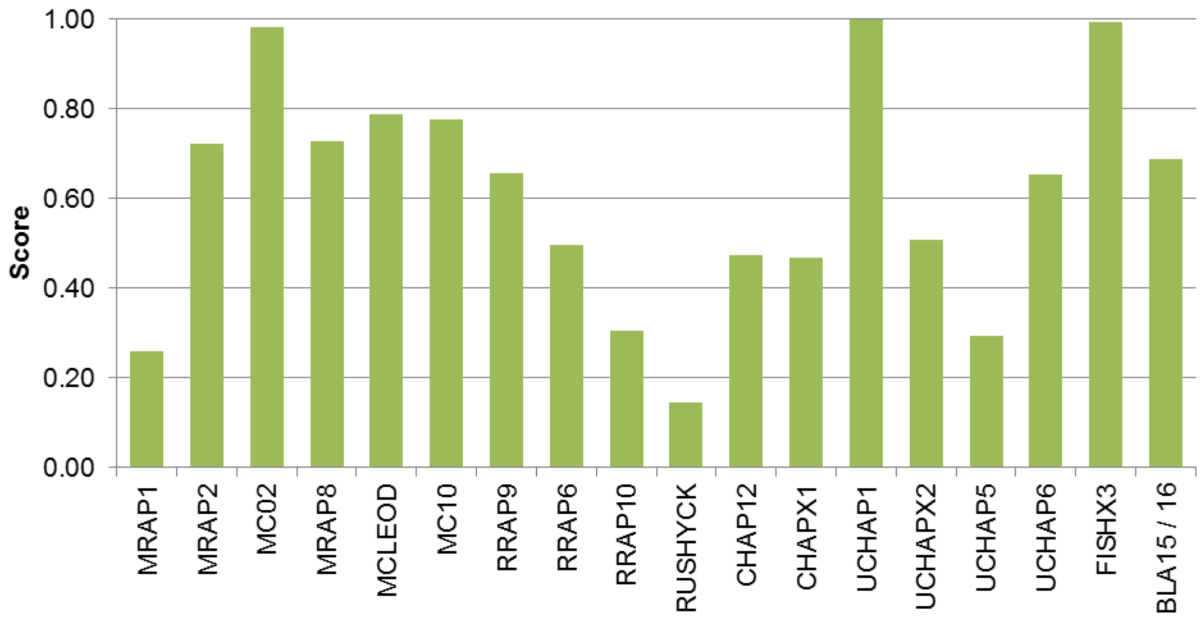


Figure 30 Extent of fringing zone sub-index scores by reach, 2011

Nativeness sub-index

The ground cover layer component scores ranged between 0.1 and 1.0, with just over half of the sites scoring in the top band (largely unmodified). Six sites were categorised as severely modified or moderately modified (Figure 31). The sites with the highest scores occurred in McLeod Creek (with the exception of MRAP1), Chapman Brook, Fisher Creek and Blackwood River, and one site each on Rushy Creek (RRAP10) and Upper Chapman Brook (UCHAP1, in a timber reserve). The lowest scores occurred on Upper Chapman Brook, two sites on Rushy Creek (RRAP9 and RUSHYCK) and one site on McLeod Creek (MRAP1).

The shrub layer component scores were relatively uniform, with all sites except one (CHAP12) being categorised in the top band (largely unmodified). Nativeness sub-index scores ranged from 0.45 to 1.0, with all reaches scoring in the top three condition bands (Figure 31).

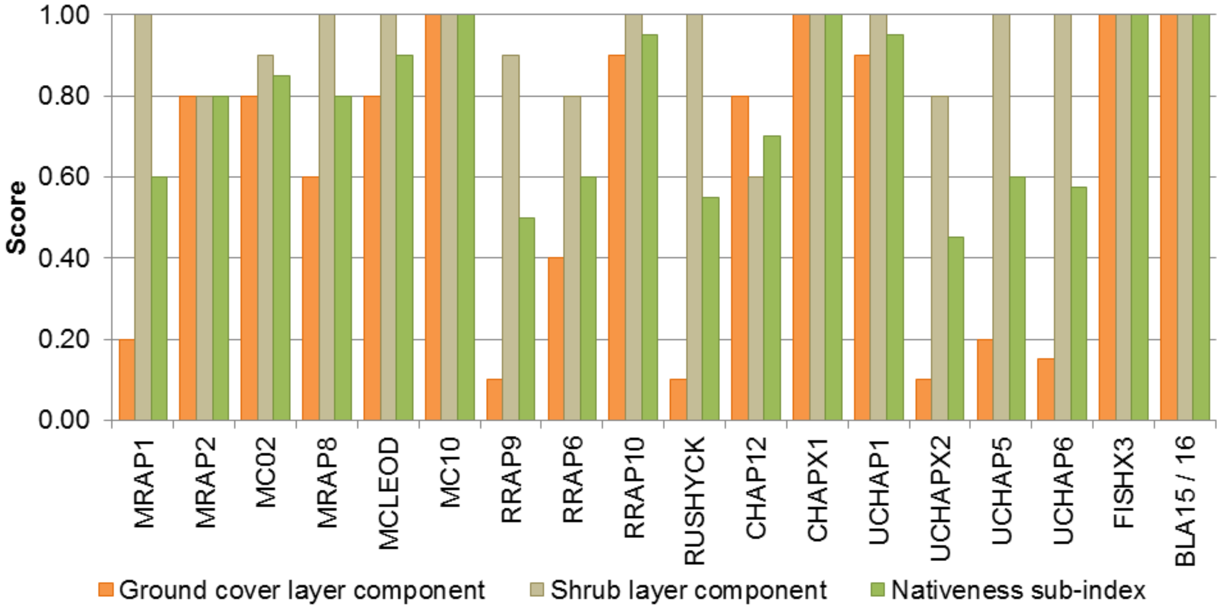


Figure 31 Nativeness sub-index and component scores by site, October 2012

Fringing zone index

The fringing zone index scores were clustered in the top three condition bands (largely unmodified, slightly modified and moderately modified) for all sites except one, RUSHYCK, which fell into the substantially modified category (Figure 32). In general, the reaches on Rushy Creek and Upper Chapman Brook scored lower than those on McLeod and Fisher creeks and the Blackwood River.

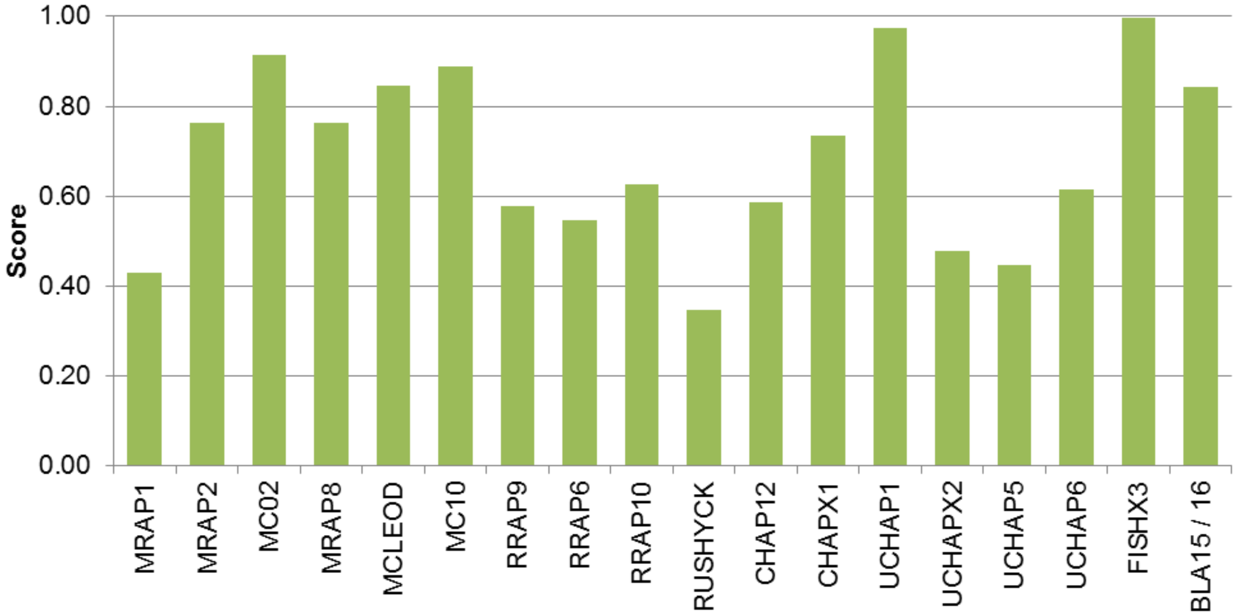


Figure 32 Fringing zone index scores by reach

Fringing zone index scores from this study were compared with 236 reaches assessed between 2008 and 2009 across south-west Western Australia (Appendix I) (data collected by Storer et al. 2011a, b). The results show that the scores for the study reaches were generally in the upper range of those occurring across the south-west, with the exception of reaches RUSHYCK, MRAP1, UCHAP5 and UCHAPX2 that were in the mid-range.

4.4 Theme: physical form

This section reviews the three sub-themes of the physical form theme: erosion, longitudinal connectivity and artificial channelisation.

4.4.1 Sub-theme: erosion

The greatest extent of erosion was observed at three sites on Rushy Creek (RRAP6, RRAP10 and RUSHYCK) and at two sites on the Upper Chapman Brook (UCHAPX2 and UCHAP5). The smallest extent of erosion was observed at sites on McLeod Creek, Chapman Brook, Fisher Creek and the Blackwood River, along with one site on Rushy Creek (RRAP9) and two sites on the Upper Chapman Brook (UCHAP1 and UCHAP6) (Table 32). At all sites, the extent of erosion was consistent on both left and right banks.

Table 32 Extent of erosion observed at each site, October 2012

		Proportion of bank length eroded (%)	
River	**Site**	**Left bank**	**Right bank**
McLeod Creek	MRAP1	0–5	0–5
	MRAP2	0–5	0–5
	MC02	0–5	0–5
	MRAP8	>5–20	>5–20
	MCLEOD	0–5	0–5
	MC10	>5–20	>5–20
Rushy Creek	RRAP9	0–5	0–5
	RRAP6	>50–100	>50–100
	RRAP10	21–50	21–50
	RUSHYCK	>50–100	>50–100
Chapman Brook	CHAP12	0–5	0–5
	CHAPX1	0–5	0–5
Upper Chapman Brook	UCHAP1	0–5	0–5
	UCHAPX2	>50–100	>50–100
	UCHAP5	>50–100	>50–100
	UCHAP6	0–5	0–5
Fisher Creek	FISHX3	0–5	0–5
Blackwood River[a]	BLA15/16	0–5	0–5

[a] *BLA 15/16 was assessed in February 2013.*

The vegetation cover provided by shrubs and trees within the first 10 m from the water's edge varied between sites (Table 33). Shrub layers were generally intact at most sites with the exception of significant clearing at RRAP9 and RRAP6, and to a lesser extent at MRAP1, MRAP2, UCHAP1 and UCHAPX2.

Tree layers provided sparse cover or were absent from three sites at mid and lower McLeod Creek (MRAP8, MCLEOD and MC10), and two sites at Rushy Creek (RRAP9 and RUSHYCK). At all remaining sites a medium to dense cover was provided by the tree layers.

Table 33 Cover of shrub and tree layer vegetation at each site, October 2012

		Shrubs (% cover)		Trees <10 m tall (% cover)		Trees >10 m tall (% cover)	
River	**Site**	**Left bank**	**Right bank**	**Left bank**	**Right bank**	**Left bank**	**Right bank**
McLeod Creek	MRAP1	>10–50	>10–50	>50–75	>50–75	>10–50	>50–75
	MRAP2	>10–50	>10–50	>75–100	>75–100	>10–50	>10–50
	MC02	>75–100	>50–75	1–10	1–10	>10–50	>10–50
	MRAP8	>75–100	>75–100	1–10	1–10	0	0
	MCLEOD	>75–100	>75–100	1–10	1–10	0	0
	MC10	>75–100	>75–100	0	0	0	0
Rushy Creek	RRAP9	1–10	1–10	1–10	1–10	0	0
	RRAP6	0	0	>10–50	>50–75	0	0
	RRAP10	>75–100	>75–100	>75–100	>75–100	0	0
	RUSHYCK	>75–100	>75–100	1–10	1–10	0	0
Chapman Brook	CHAP12	>75–100	>75–100	1–10	>10–50	1–10	>50–75
	CHAPX1	>75–100	>75–100	1–10	1–10	>10–50	>10–50
Upper Chapman Brook	UCHAP1	>10–50	>10–50	>10–50	>10–50	>50–75	>50–75
	UCHAPX2	>10–50	>10–50	>10–50	>10–50	>10–50	>50–75
	UCHAP5	>50–75	>50–75	>10–50	>10–50	>75–100	>75–100
	UCHAP6	>75–100	>75–100	>50–75	>50–75	0	1–10
Fisher Creek	FISHX3	>75–100	>75–100	>10–50	>10–50	>50–75	>50–75
Blackwood River[a]	BLA15/16	>50–75	>50–75	1–10	1–10	>50–75	>50–75

Notes: [a] *BLA 15/16 was assessed in February 2013.*

Shading indicates levels of cover: dense, moderate, sparse and absent; these descriptions were devised for this study to assist with discussing the data.

4.4.2 Sub-theme: longitudinal connectivity

No major dams were located on or within 40 km of any of the reaches in the study area (Table 34). Nineteen minor dams were mapped on reaches within the study area, with the highest number occurring on reach CHAP12. A further four minor dams were located within 20 km of the start or end of the study reaches (MC10, RUSHYCK, UCHAP1 and BLA 15/16).

There were two gauging stations on the study reaches, both of which are on the Chapman Brook (reach CHAPX1). In addition there were four gauges located upstream or downstream of study reaches; these are located on the Chapman and Upper Chapman brooks and the Blackwood River.

The density of locations where road or railway infrastructure crosses a watercourse varies from between 1.6 crossings/km (MRAP1) to 0 crossings/km (MC10 and BLA15/16).

Table 34 Number or density of potential barriers within 40 km of the ends of each reach, 2009

River	Reach	Major dams	Minor dams	Gauging stations	Road or rail crossing density (#/km)
McLeod Creek	MRAP1	none	none	none	1.6
	MRAP2	none	1 on reach[a]	none	0.8
	MC02	none	none	none	0.9
	MRAP8	none	2 on reach	none	1.4
	MCLEOD	none	none	none	0.4
	MC10	none	1 ~3 km d/s[b]	none	0.0
Rushy Creek	RRAP9	none	2 on reach	none	1.0
	RRAP6	none	2 on reach	none	0.5
	RRAP10	none	4 on reach	none	0.5
	RUSHYCK	none	1 ~1 km u/s[c]	none	0.5
Chapman Brook	CHAP12	none	9 on reach	1 ~6 km d/s	1.1
	CHAPX1	none	4 on reach	2 on reach	0.7
Upper Chapman Brook	UCHAP1	none	1 ~2 km d/s	1 ~13 km d/s	0.4
	UCHAPX2	none	2 on reach	1 ~3.6 km d/s	0.4
	UCHAP5	none	2 on reach	1 ~6 km d/s	0.8
	UCHAP6	none	2 on reach	1 ~0.5 km d/s	0.6
Fisher Creek	FISHX3	none	none	none	0.4
Blackwood River	BLA15/16	none	1 ~12.5 km u/s	1 ~1.6 km d/s	0.0

Notes:

[a] Barrier not listed in stream barrier geodatabase but observed in field.

[b] d/s = downstream of the end of the reach; u/s = upstream of the start of the reach.

[c] An additional barrier was observed on the reach however it has a low-flow bypass channel and fishway, therefore was not considered a significant barrier for this assessment (see Section 5.2).

4.4.3 Sub-theme: artificial channel

All of the study reaches were mapped as watercourse line (natural channel), with no features mapped as canal line (artificial channel with straightened form) (Appendix K).

4.4.4 Scores: physical form index

Erosion sub-index

The erosion extent component score for 13 of the 18 sites was in the top two condition bands (largely unmodified and slightly modified). The remaining five sites (in Rushy Creek and Upper Chapman Brook) scored in the lowest two condition bands (severely modified and substantially modified) (Figure 33 and Appendix H).

The bank stabilisation component scores across all study sites were predominantly within the moderately modified condition band or lower; only FISHX3, UCHAP5, MRAP2 and RRAP10 scored higher. Bank stability at Rushy Creek sites RRAP9 and RRAP6 and McLeod Creek site MC10 was notably low.

When combined, the component scores resulted in erosion sub-index scores that covered all five condition bands, although most sites were in the top three condition bands (moderately modified, slightly modified and largely unmodified). The scores were lower for the Rushy Creek sites and two of the four Upper Chapman Brook sites than for the remaining study sites.

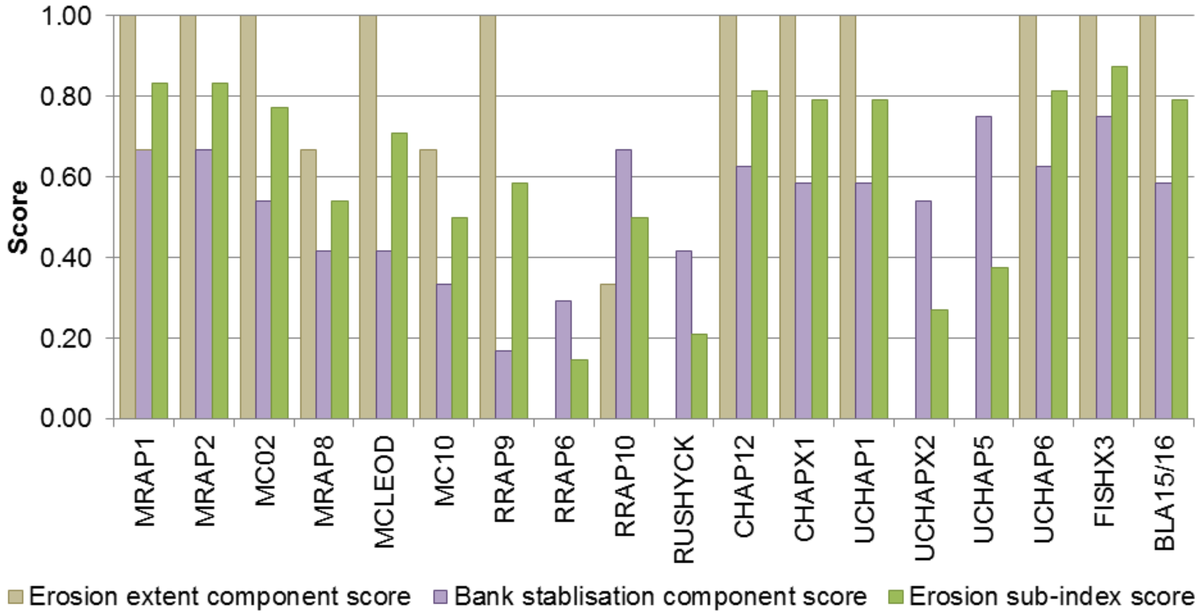


Figure 33 Erosion sub-index and component scores by site, October 2012

Longitudinal connectivity sub-index

The longitudinal connectivity sub-index scores ranged from 0.46 (CHAPX1) to 0.97 (MCLEOD), with half of the sites scoring in the slightly modified condition band (Table 35). Chapman and Upper Chapman brooks had the lowest scores due to the combination of minor dams and gauging stations located on or close to those reaches. McLeod Creek (reaches MRAP1, MC02 and MCLEOD) and Fisher Creek (FISHX3) had the highest scores due to the absence of dams and gauging stations in these reaches.

Table 35 Longitudinal connectivity sub-index and component scores by reach, 2009

Reach	Longitudinal connectivity sub-index score	Major dams component score	Minor dams component score	Gauging stations component score	Road/rail crossings component score
MRAP1	0.95	1.00	1.00	1.00	0.50
MRAP2	0.67	1.00	0	1.00	0.75
MC02	0.97	1.00	1.00	1.00	0.75
MRAP8	0.64	1.00	0	1.00	0.50
MCLEOD	0.97	1.00	1.00	1.00	0.75
MC10	0.77	1.00	0.25	1.00	1.00
RRAP9	0.64	1.00	0	1.00	0.50
RRAP6	0.67	1.00	0	1.00	0.75
RRAP10	0.67	1.00	0	1.00	0.75
RUSHYCK	0.74	1.00	0.25	1.00	0.75
CHAP12	0.54	1.00	0	0.50	0.50
CHAPX1	0.46	1.00	0	0	0.75
UCHAP1	0.64	1.00	0.25	0.50	0.75
UCHAPX2	0.51	1.00	0	0.25	0.75
UCHAP5	0.56	1.00	0	0.50	0.75
UCHAP6	0.51	1.00	0	0.25	0.75
FISHX3	0.97	1.00	1.00	1.00	0.75
BLA15/16	0.69	1.00	0.50	0.25	1.00

Notes: shading indicates condition band: largely unmodified 0.8–1.00, slightly modified 0.6–0.79, moderately modified 0.4–0.59, substantially modified 0.2–0.39, severely modified 0–0.19

Artificial channel sub-index

All sites scored 1.0 for the artificial channel sub-index (Appendix H).

Physical form index

The physical form index scores for all reaches were in the top three condition bands (moderately modified, slightly modified and largely unmodified, Figure 34). Reaches of Rushy Creek and Upper Chapman Brook had the lowest scores, while the highest scores were for reaches of Fisher and McLeod creeks.

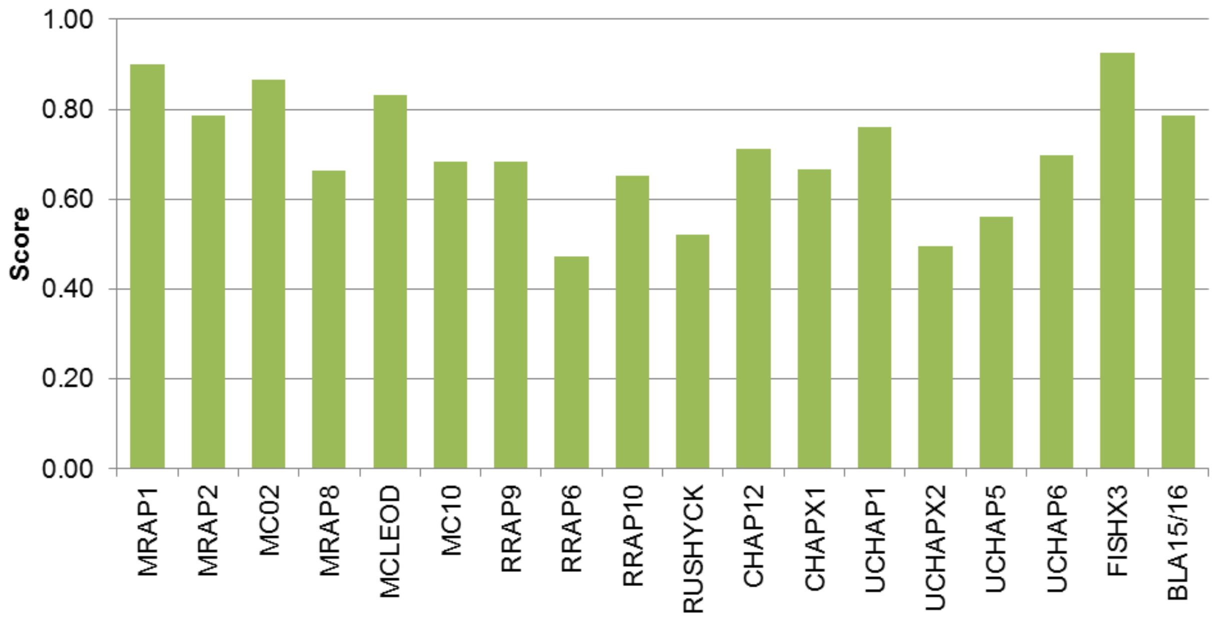


Figure 34 Physical form index scores by reach

The physical form index scores generated for reaches in this study were compared with 234 reaches assessed between 2008 and 2009 across south-west Western Australia (Appendix I) (data collected by Storer et al. 2011a, b). The results show that the scores for the study reaches were distributed across the range of scores for the south-west reaches. Scores for Rushy Creek reaches were lower than many reaches in the south-west, while the score for the Fisher Creek reach was one of the highest across the south-west.

4.5 Theme: water quality

This section reviews the seven sub-themes of the water quality theme: nitrogen, phosphorus, turbidity, diel dissolved oxygen, diel temperature, salinity and non-nutrient contaminants.

All water quality data are presented in Appendix L.

Due to insufficient water, water quality sampling was not conducted at:

- UCHAP1 in June and October 2012
- MC02, CHAP12, CHAPX1, UCHAP1, UCHAP6 or FISHX3 in February 2013.

4.5.1 Sub-theme: nitrogen

Total nitrogen concentrations ranged from 0.1 to 4.1 mg/L across the three sampling occasions. The mean value for all sites was lower in October 2012 (0.5 ± 0.3 mg/L) than June 2012 and February 2013 (1.5 ± 1.1 mg/L and 1.4 ± 1.5 mg/L respectively) (Table 36).

Total nitrogen recorded in June 2012 was above the guideline trigger value of 1.2 mg/L (ANZECC & ARMCANZ 2000a) at 6 of the 10 sites sampled (MC02, MC10, CHAPX2, UCHAPX2, UCHAP5 and UCHAP6), with the highest value of 4.1 mg/L recorded at UCHAP5.

All total nitrogen concentrations recorded in October 2012 were below the guideline trigger value. In general, the total nitrogen levels measured in October 2012 were slightly higher in Rushy Creek than McLeod Creek and Chapman Brook. Levels in the Upper Chapman sites were more variable than the other catchments, ranging from 0.24 mg/L (UCHAPX2) to 1.1 mg/L (UCHAP5). The lowest total nitrogen value was recorded at Fisher Creek at 0.08 mg/L (FISHX3).

In February 2013, total nitrogen was above the guideline trigger value at two of the six sites sampled – MC10 and BLA16X.

Table 36 Total nitrogen concentration recorded at sites, 2012 to 2013

River	Site	June 2012 (mg/L)	October 2012 (mg/L)	February 2013 (mg/L)
McLeod Creek	MRAP1	n/a	0.69	n/a
	MRAP2	n/a	0.45	n/a
	MC02	2.1	0.25	dry
	MRAP8	n/a	0.49	n/a
	MCLEOD	n/a	0.51	n/a
	MC10	1.4	0.69	3.3
Rushy Creek	RRAP9	n/a	0.62	n/a
	RRAP6	n/a	0.48	n/a
	RRAP10	n/a	0.98	n/a
	RUSHYCK	n/a	0.81	n/a
Chapman Brook	CHAP12	1.9	0.53	dry
	CHAPX1	1.1	0.33	dry
Upper Chapman Brook	UCHAP1	dry	stationary	dry
	UCHAPX2	1.3	0.24	0.2
	UCHAP5	4.1	1.1	1.1
	UCHAP6	1.4	0.32	dry
Fisher Creek	FISHX3	0.14	0.08	dry
Blackwood River	BLA15	0.91	0.54	0.37
	BLA16	0.96	0.56	0.35
	BLA16X	n/a	n/a	3.3

Note: shading indicates total nitrogen concentration exceeded the guideline trigger value of 1.2 mg/L (ANZECC & ARMCANZ 2000a).

In samples where the total nitrogen exceeded the guideline, total oxidised nitrogen was the dominant nitrogen species, accounting for more than 75% of the total nitrogen at all sites except one (Table 37). At CHAP12, the proportion of total oxidised nitrogen was lower than the other sites (53%), and the proportion of dissolved organic nitrogen was higher than at all other sites (44%). The concentration of dissolved organic nitrogen recorded at CHAP12 was the highest of the 10 sites sampled in June 2012 at 0.84 mg/L, which was over two and half times higher than the next highest concentration recorded (0.29 mg/L at MC10) (Appendix L).

Table 37 Component species as a percentage of total nitrogen for sites where total nitrogen exceeded the guideline (ANZECC & ARMCANZ 2000a), 2012 to 2013

Date	River	Site	Dissolved organic nitrogen (%)	Total oxidised nitrogen (%)	Nitrogen as ammonia/ ammonium (%)	Particulate nitrogen (%)
June 2012	McLeod Creek	MC02	7	93	0	0
		MC10	20	79	1	0
	Chapman Brook	CHAP12	44	53	0	3
	Upper Chapman Brook	UCHAPX2	14	77	1	8
		UCHAP5	4	95	1	0
		UCHAP6	7	92	1	0
February 2013	McLeod Creek	MC10	22	76	2	0
	Chapman Brook	CHAP12	6	94	0	0

4.5.2 Sub-theme: phosphorus

Total phosphorus concentrations ranged between 0 and 0.05 mg/L across the sites for all the sampling occasions (Appendix L); all values were below the guideline trigger value of 0.065 mg/L (ANZECC & ARMCANZ 2000a).

4.5.3 Sub-theme: turbidity (including total suspended solids)

Turbidity ranged between 1.0 and 30.0 NTU across the study area (Table 38), with the mean average being similar in June 2012 and October 2012 (5.3 ± 8.7 NTU and 5.1 ± 5.8 NTU respectively) and higher than in February 2013 (2.3 ± 1.5 NTU).

With the exception of two samples, all turbidity values were below the guideline trigger value of 10 to 20 NTU (ANZECC & ARMCANZ 2000a). The exceptions were a turbidity of 30 NTU measured at UCHAP5 in June 2012 and 27 NTU at RRAP10 in October 2012.

Total suspended solids ranged between 0.5 to 36 mg/L across the study area, and with the exception of two samples, all values were below the Department of Water interim guideline trigger value of 6 mg/L (DoW unpublished data). The exceptions were concentrations of 32 mg/L measured at UCHAP5 in June 2012 and 36 mg/L at RRAP10 in October 2012, which coincided with the high turbidity values.

Table 38 Turbidity recorded sites, 2012 to 2013

River	Site	June 2012 (NTU)	October 2012 (NTU)	February 2013 (NTU)
McLeod Creek	MRAP1	n/a	3.3	n/a
	MRAP2	n/a	1.2	n/a
	MC02	1.8	1.6	dry
	MRAP8	n/a	6.2	n/a
	MCLEOD	n/a	5.5	n/a
	MC10	2.7	5.6	1.5
Rushy Creek	RRAP9	n/a	7.2	n/a
	RRAP6	n/a	6.1	n/a
	RRAP10	n/a	27.0	n/a
	RUSHYCK	n/a	3.6	n/a
Chapman Brook	CHAP12	4.2	5.3	dry
	CHAPX1	1.2	3.6	dry
Upper Chapman Brook	UCHAP1	dry	stationary	dry
	UCHAPX2	3.6	1.5	5.2
	UCHAP5	30.0	1.0	2.5
	UCHAP6	2.6	1.5	dry
Fisher Creek	FISHX3	1.9	3.7	dry
Blackwood River	BLA15	2.2	3.5	1.1
	BLA16	2.4	3.7	1.1
	BLA16X	n/a	n/a	2.5

Note: shading indicates that the turbidity exceeded the guideline trigger value of 10 – 20 NTU (ANZECC & ARMCANZ 2000a).

4.5.4 Sub-theme: diel dissolved oxygen

During October 2012 sampling, the greatest diurnal range of dissolved oxygen was recorded at MRAP1, where the concentration fluctuated from 2.8 to 11.1 mg/L (range of 8.4 mg/L) (Figure 35). Dissolved oxygen concentrations were around or above the guideline value of 5.0 mg/L (Kohen & O'Connor 1990) at all sites except MRAP1 and CHAPX1. At MRAP1, in McLeod Creek, concentrations were below 5.0 mg/L for 12 hours (6pm to 6am) and reached a minimum of 2.8 mg/L. At CHAPX1, in Chapman Brook, concentrations were just below 5.0 mg/L for approximately two hours (reaching a minimum concentration of 4.95 mg/L).

During February 2013, the greatest diurnal range was recorded at UCHAPX2, where dissolved oxygen ranged from 1.7 to 5.3 mg/L (range of 3.7 mg/L) (Figure 36). Dissolved oxygen was below or around 5.0 mg/L at one site, UCHAPX2, for the whole 24 hours sampled, with a maximum value of 5.4 mg/L and a minimum of 1.7 mg/L.

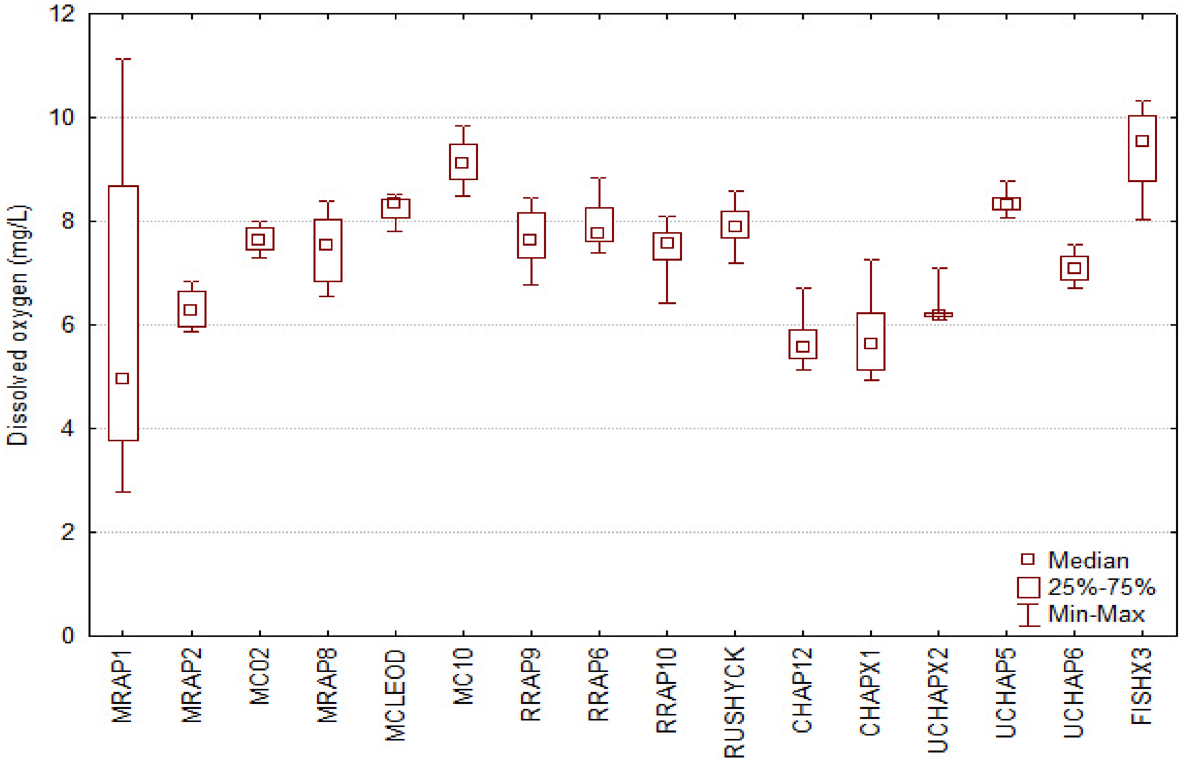


Figure 35 Diel dissolved oxygen concentrations recorded at sites, October 2012

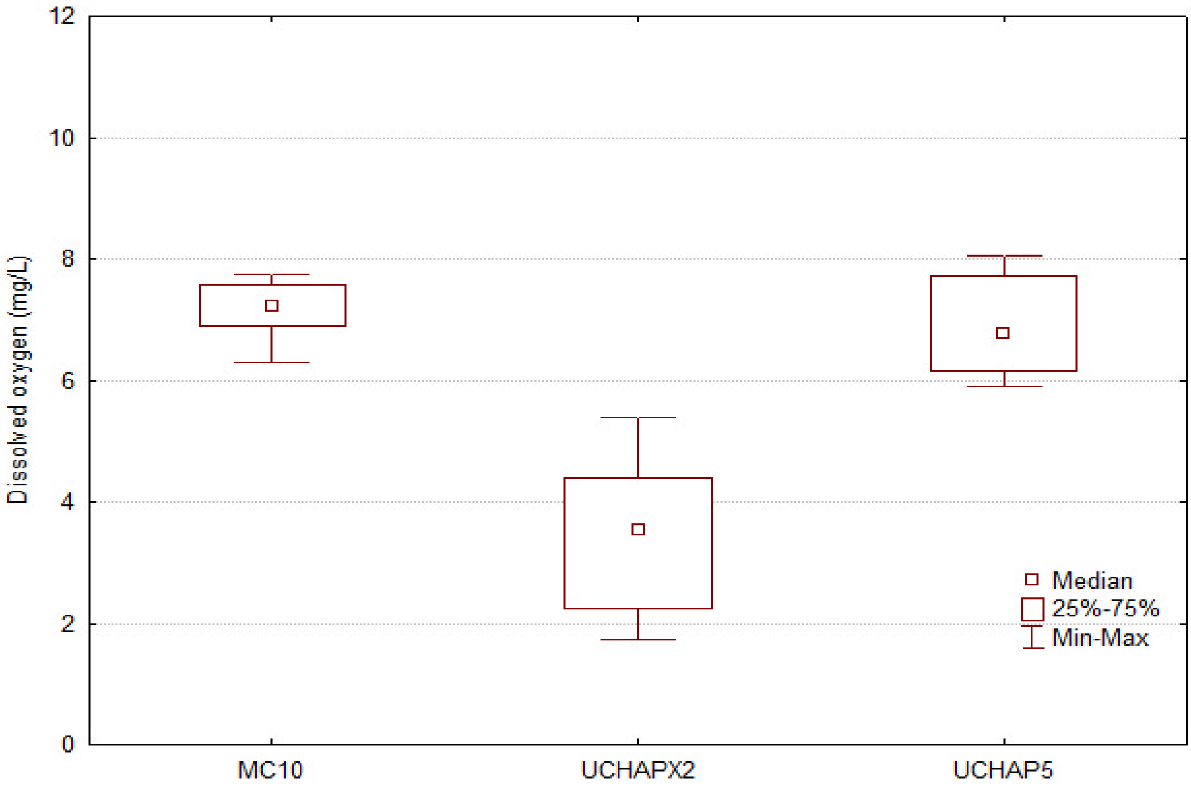


Figure 36 Diel dissolved oxygen concentrations recorded at sites, February 2013

4.5.5 Sub-theme: diel temperature

During October 2012, the water temperature at the sites sampled ranged from a minimum of 11.5 °C to 26.4 °C, with a mean minimum of 14.7 °C (± 1.9 °C) and a mean maximum of 19.0 °C (± 2.7 °C). The greatest diel temperature range was recorded at MRAP1, where the water temperature fluctuated from 13.0 to 26.4 °C (range of 13.4 °C) (Figure 37). The temperature range exceeded the 4.0 °C guideline value (Storer et al. 2011b) at 6 of the 16 sites sampled – MRAP1, MRAP8, RRAP9, RUSHYCK, CHAP12 and FISHX3 (Figure 37), however the only significantly large range was measured at MRAP1 where temperature fluctuated by 13.0 °C; at the remaining five sites the maximum range was 6.4 °C.

During February 2013, the water temperature at the sites sampled ranged from 18.9 °C to 26.2 °C, with a mean minimum of 20.9 °C (± 2.0 °C) and a mean maximum of 24.0 °C (± 2.2 °C). The diel temperature range was less than guideline value of 4 °C at all three sites sampled; the greatest diel range was recorded at MC10, where water temperature ranged from 23.0 to 26.1 °C (range of 3.1 °C) (Figure 38).

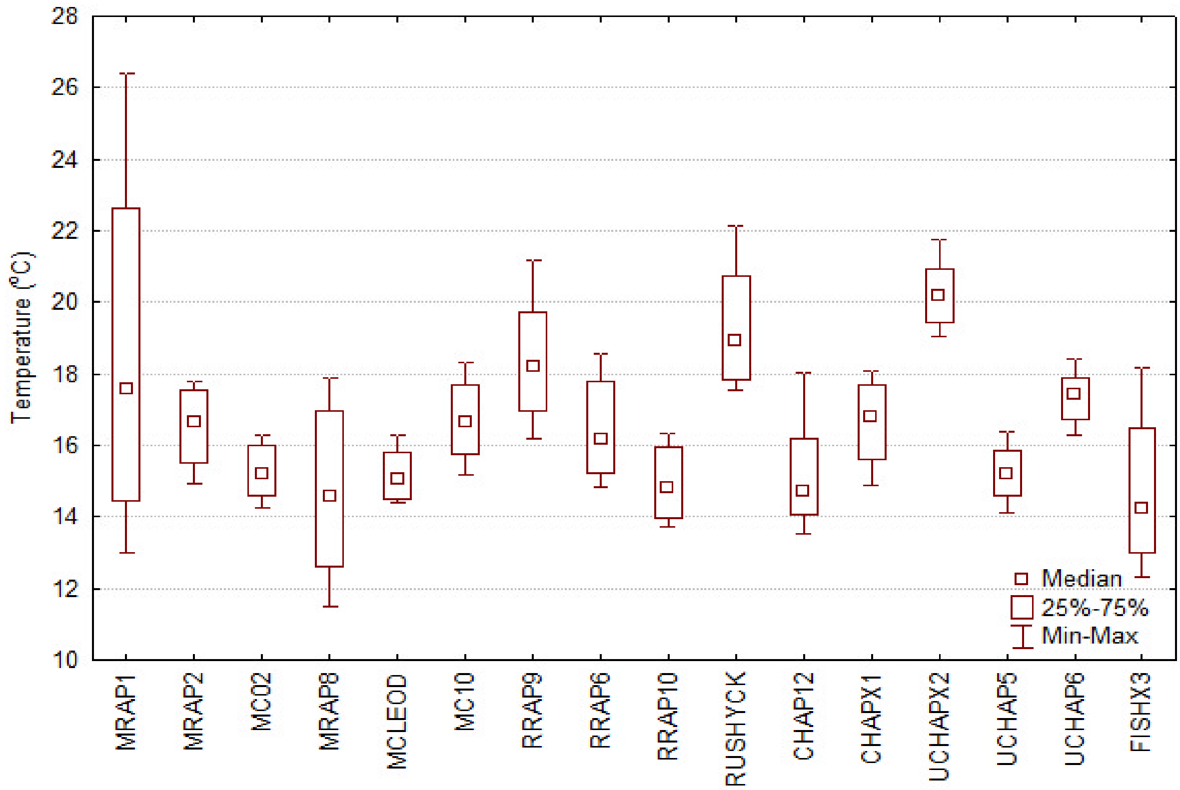


Figure 37 Diel temperature recorded at sites, October 2012

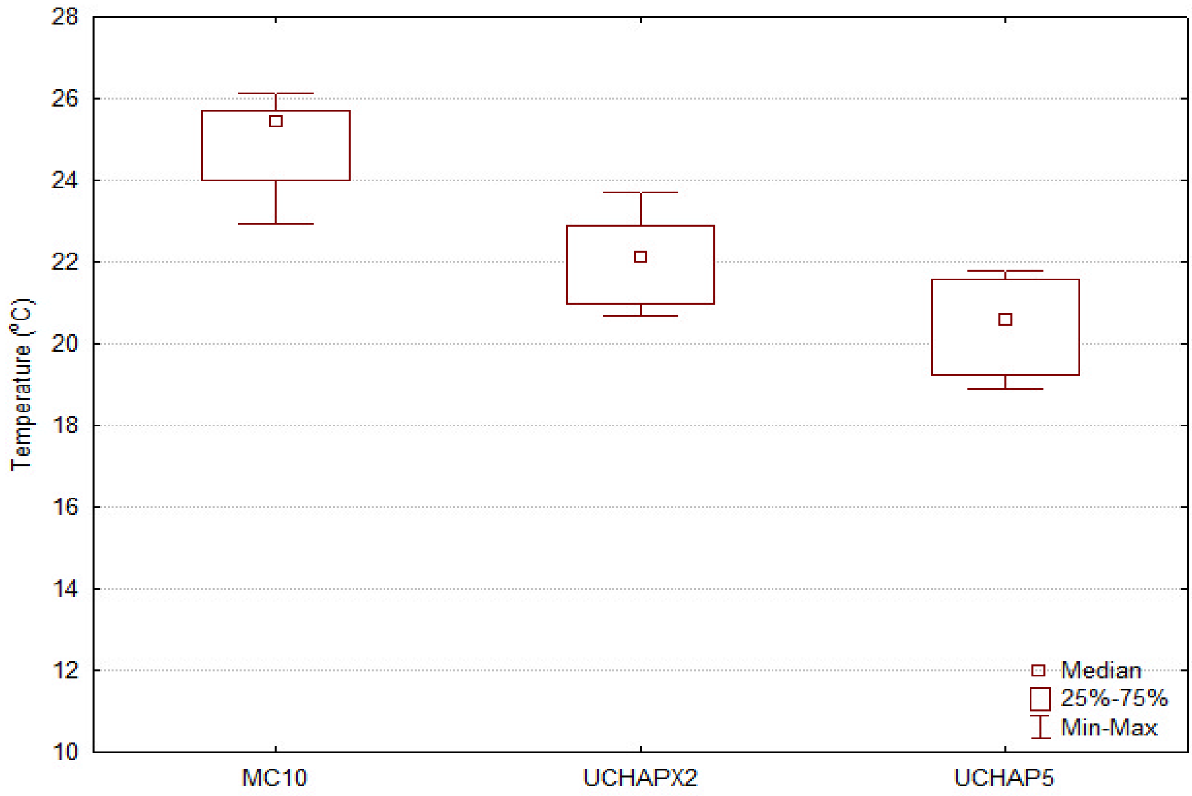


Figure 38 Diel temperature recorded at sites, February 2013

4.5.6 Sub-theme: electrical conductivity (salinity)

Based on the stream salinity status dataset (see Appendix Z), salinity classifications were available for 12 of the 18 study reaches, all of which were categorised as <500 mg/L TDS (Table 39).

Based on contextual data collected in the field, electrical conductivity ranged from 329 to 6910 µS/cm across all sites and sampling occasions (Table 39).

Salinity concentrations (estimated from electrical conductivity) in the tributaries were categorised[7] as fresh, with the exception of two samples: the concentration at Fisher Creek (FISHX3) in June 2012 was 847 mg/L TDS (marginal), and the concentration at MC10 in McLeod Creek in February 2013 was 3760 mg/L TDS (moderately saline). For all tributary sites except MC10 in February 2013, the concentration was below the guideline value for freshwater of 1000 mg/L proposed by Hart et al. (1991).

Salinity concentrations in the Blackwood River sites (BLA15 and BLA16) were categorised as moderately saline on all three sampling occasions. Note: given the tidal influence in the Blackwood River extends approximately 42 km inland (Hodgkin 1978) the guideline value for freshwater proposed by Hart et al. (1991) is not applicable for these sites.

[7] The classification devised by Mayer et al. (2005) has been used in this report.

Table 39 Salinity categories for reaches 1985 to 2002 and electrical conductivity and estimated salinity at sites 2012 to 2013

River	Reach & site	1985-2002 Salinity (mg/L TDS) [a]	June 2012 EC (µS/cm) [b]	June 2012 Salinity (mg/L TDS) [c]	October 2012 EC (µS/cm)	October 2012 Salinity (mg/L TDS)	February 2013 EC (µS/cm)	February 2013 Salinity (mg/L TDS)
McLeod Creek	MRAP1	< 500	n/a	n/a	no data	no data	n/a	n/a
	MRAP2	< 500	n/a	n/a	no data	no data	n/a	n/a
	MC02	< 500	531	361	464	316	dry	dry
	MRAP8	no data	n/a	n/a	no data	no data	n/a	n/a
	MCLEOD	< 500	n/a	n/a	445	303	n/a	n/a
	MC10	< 500	630	428	471	320	5530	3760
Rushy Creek	RRAP9	no data	n/a	n/a	no data	no data	n/a	n/a
	RRAP6	no data	n/a	n/a	598	407	n/a	n/a
	RRAP10	< 500	n/a	n/a	623	424	n/a	n/a
	RUSHYCK	< 500	n/a	n/a	522	355	n/a	n/a
Chapman Brook	CHAP12	< 500	421	286	397	270	dry	dry
	CHAPX1	< 500	447	304	442	301	dry	dry
Upper Chapman Brook	UCHAP1	no data	dry	dry	382	260	dry	dry
	UCHAPX2	no data	516	351	418	284	542	369
	UCHAP5	< 500	329	224	371	252	452	307
	UCHAP6	< 500	513	349	430	292	dry	dry
Fisher Creek	FISHX3	< 500	1245	847	710	483	dry	dry
Blackwood River	BLA15	unknown	3150	2142	5050	3434	6880	4678
	BLA16	unknown	3260	2217	4970	3380	6910	4699
	BLA16X	n/a	n/a	n/a	n/a	n/a	333	226

Notes:
[a] from Mayer et al. 2005
[b] Electrical conductivity compensated to 25 °C.
[c] Estimated salinity (TDS (mg/L) = 0.68 x EC (µS/cm) (ANZECC & ARMCANZ 2000b).
Shading indicates classification of salinity (adapted from Hillel 2000, cited in Mayer et al. 2005): fresh <500 mg/L, marginal 500–1000 mg/L TDS, moderately saline, 2000–5000 mg/L TDS.

4.5.7 Sub-theme: non-nutrient contaminants

Sediment chemistry

Bioavailable metals (aluminium, chromium, copper, iron, lead and zinc) were present in the sediment, although concentrations did not exceed guidelines (ANZECC & ARMCANZ 2000a) (Appendix N).

Organochlorine and organophosphate pesticides were not present in concentrations above the limits of reporting (Appendix O, P).

Particle size analysis

Sediment collected from each site consisted of particles from the spectrum of size categories according to the Wentworth scale (Wentworth 1922). The Upper Chapman Brook sites (UCHAP1, UCHAP5 and UCHAP6) had a higher proportion of finer fraction sediment (silt and fine sand) than the Chapman Brook site (CHAP12), which was predominantly coarse sand and gravel (Appendix Q).

Water chemistry

Herbicides were not detected in water at concentrations above limits of reporting (Appendix R).

4.5.8 Scores: water quality index

Scores for the sub-indices of the water quality index, calculated for October 2012, are presented in Appendix H. Scores ranged from 0.4 to 1.0 and were categorised in the top three condition bands (largely unmodified to moderately modified).

The water quality index scores were in the top condition band (largely unmodified) for all sites except two: MRAP1 and RRAP10 (Figure 39). At MRAP1 the water quality index score of 0.71 (slightly modified) reflects the high diurnal temperature range and low dissolved oxygen measured at this site in October 2012. At RRAP10, the high turbidity value is reflected in the score of 0.70 (slightly modified).

Water quality index scores from this study were compared with 95 reaches assessed between 2008 and 2009 across south-west Western Australia (Appendix I) (data collected by Storer et al. 2011a, b). The results show the scores for the study reaches were within the upper range of those occurring across the south-west.

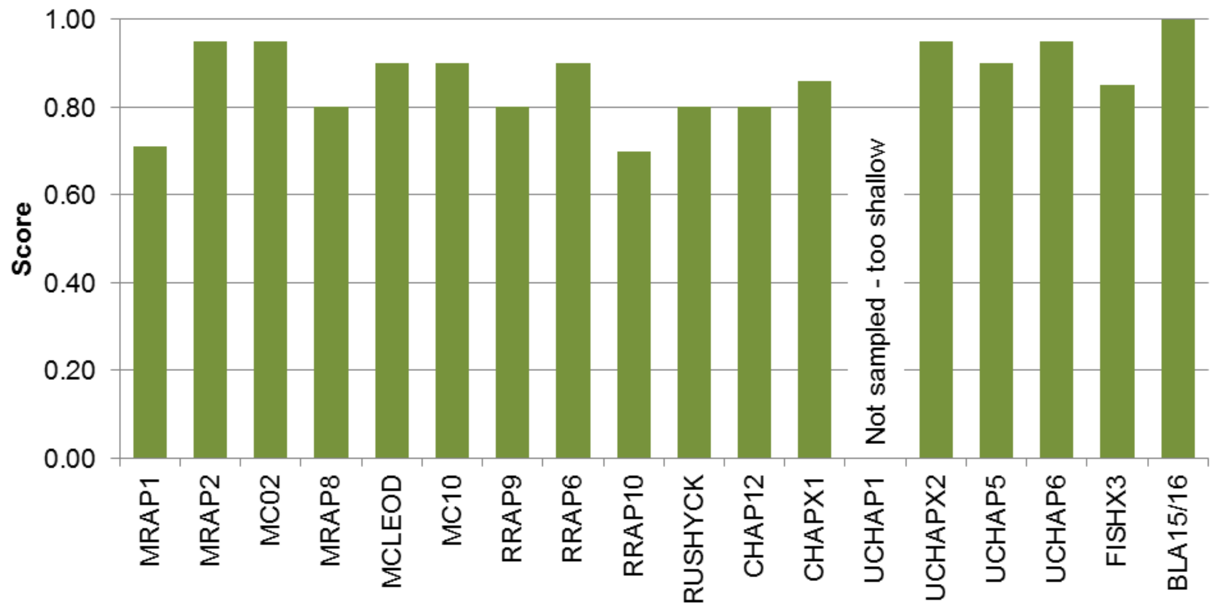


Figure 39 Water quality index scores by reach

4.6 Theme: aquatic biota

This section reviews the two sub-themes of the aquatic biota theme: fish and crayfish and macroinvertebrates.

4.6.1 Sub-theme: macroinvertebrates

Richness and abundance

A total of 102 taxa were collected in this study (Appendix X). Taxa richness varied between 39 (MCLEOD on McLeod Creek) and seven (RRAP10 on Rushy Creek). Abundance ranged from 26 individuals (RRAP10 on Rushy Creek) to 2522 individuals (RRAP9 on Rushy Creek) (Figure 40).

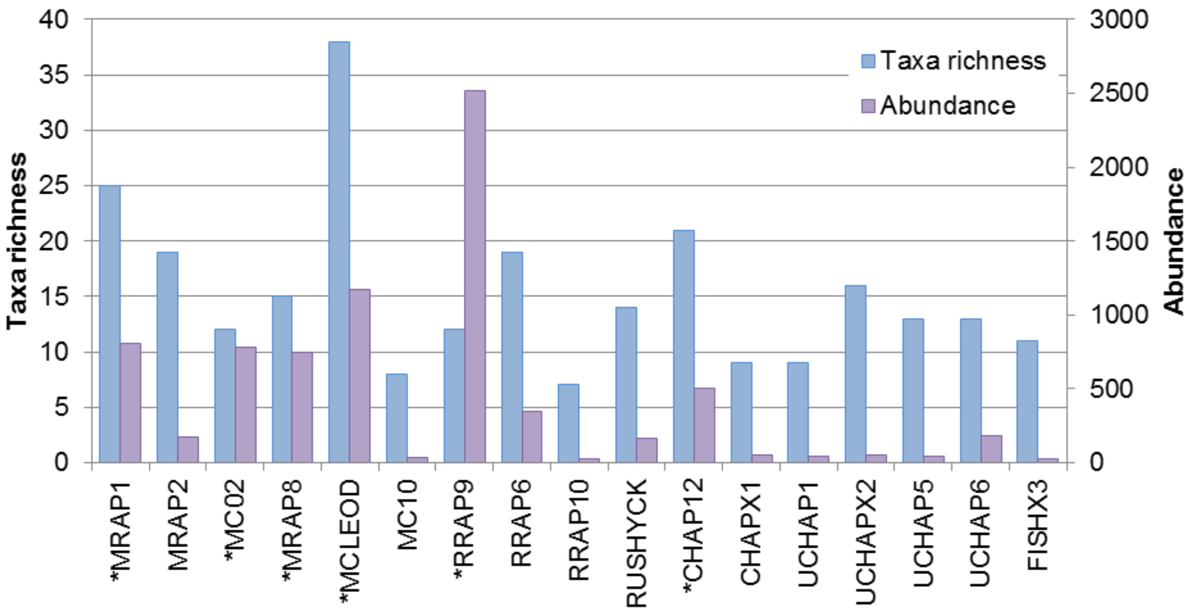


Figure 40   Macroinvertebrate richness and abundance by site, October 2012

*Note: * abundance was estimated from the sub-sample (see Section 3.4.6).*

Notable taxa collected

Two new larval forms of *Notoperata* (caddisfly larvae) were collected during this study (from three sites on McLeod Creek: MRAP8, MC02 and MCLEOD, and one on the Upper Chapman: UCHAP6). These larval forms have not previously been described, so it is not yet known whether they belong to an already described species or an undescribed species (Rosalind St Clair pers. comm. 2013).

Two caddisfly larvae species were collected that Sutcliffe (2003) suggests are endangered: *Notoperata sp. AV4* at MCLEOD and *Triplectides neveipennis AV21* at four sites (MRAP2, MCLEOD, RRAP6 and FISHX3) in low numbers (maximum of six individuals per site).

The stonefly, *Riekaperla occidentalis,* was found in McLeod Creek at MRAP8. This species is endemic to the south-west (WRM 2009).

The stonefly larvae *Newmanoperla exigua (*with Gondwanic affinities, WRM 2009), was collected in this study (MRAP2 and MCLEOD in McLeod Creek).

In addition to the macroinvertebrates collected in the samples, freshwater mussels (*Westralunio carteri*) were observed in October 2012 at McLeod Creek (MCLEOD) and Upper Chapman Brook (UCHAP1, UCHAP5 and UCHAPX2). This mussel is listed as Priority 4 (rare, near threatened and other species in need of monitoring) by DPaW (2013).

Several of the species collected are believed to be endemic to south-west Western Australia though they are widespread in the area; it is possible that more locally endemic species are present as not all taxa could be identified to species and the distribution of many species is poorly known (Emma van Looij pers. comm. 2013).

Community composition

Insecta (insects) was the most abundant class at all sites, followed by Crustacea (shrimps, amphipods) – which accounted for over a third of the abundance at sites MC02, MC10 and UCHAP1. Arachnida (water mites, aquatic spiders), Gastropoda (snails) and Oligochaeta (segmented worms) were also present, along with animals grouped as 'other' in (Figure 41): Collembola (springtails), Nematoda (round worms), Nemertea (ribbon worms) and Turbellaria (flat worms).

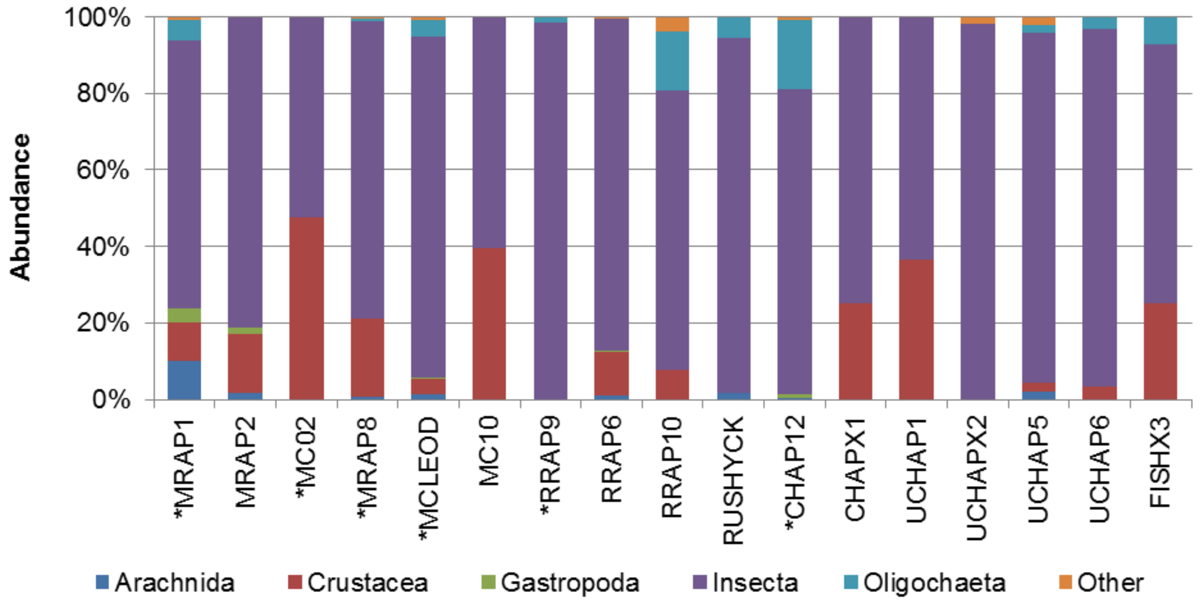


Figure 41 Proportion of macroinvertebrate abundance by class and site, October 2012

*Note: * abundance was estimated from the sub-sample (see Section 3.4.6).*

Of the 102 distinct taxa collected, 48 were found at only one site. Further, there was no common taxon across all sites. The most widely distributed taxon was *Tanytarsus* sp. (a non-biting midge larvae) which was found at 15 of the 17 sites. This species also generally had the highest abundance.

Within the Insecta class, 19 EPT taxa (Ephemeroptera: mayflies; Plecoptera: stoneflies; Trichoptera: caddisflies) were found in this study. The highest number of EPT taxa were found at MCLEOD (eight taxa), while sites UCHAP1 and MC10 had only one EPT taxa each. They were entirely absent from site RRAP10. The highest abundance of EPT taxa was found at site RRAP9, with 256 individuals from two species (*Tasmanocoenis tillyardi* and *Hellyethira* sp.). Site CHAPX1 had the highest proportion of EPT taxa, where they contributed just under half of the total abundance (Figure 42).

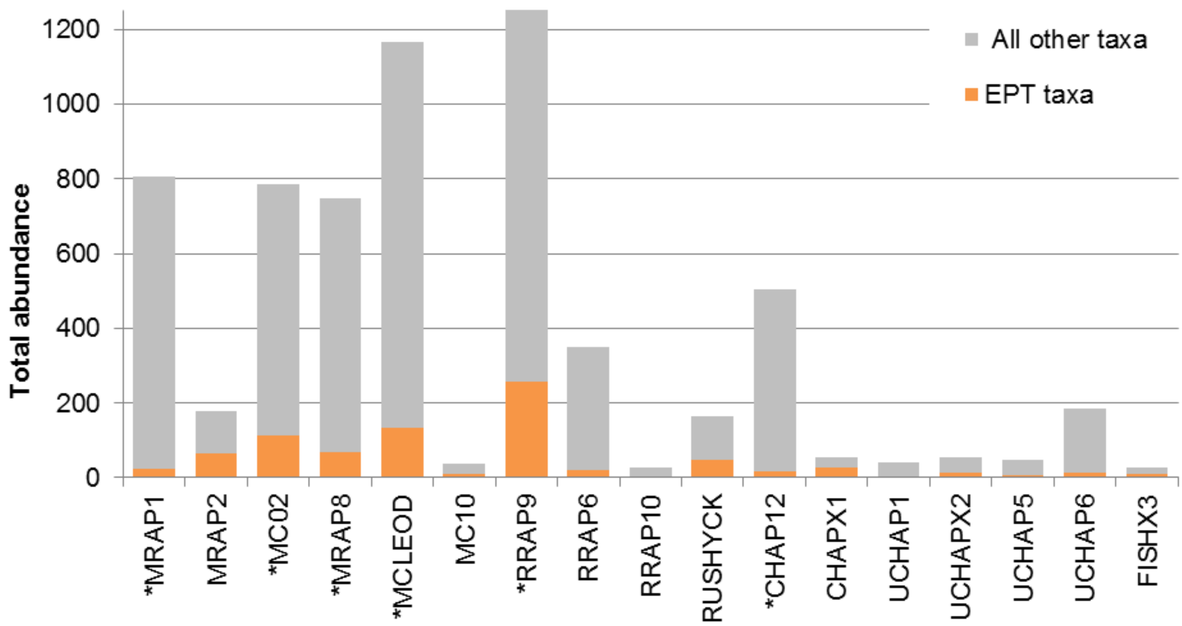


Figure 42 Abundance of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa and all other taxa (all classes) by site, October 2012

*Note: * abundance was estimated from the sub-sample (see Section 3.4.6).*

Trophic structure

The trophic structure varied across the sites and river systems (Figure 43). At most sites animals from the four functional feeding groups were present: exceptions were MC10, RRAP9 and UCHAPX2 where shredders were absent, RRAP10 where predators were absent, and UCHAP1 and FISHX3 where grazers were absent.

Collectors ranged from 21% of the total abundance (CHAPX1, FISHX2) to 85% (UCHAP6). They were the most abundant group at 12 of the 17 sites. At the remaining five sites:

- shredders were dominant (≥ 50% abundance) at MRAP2, MC02 and FISHX3
- CHAPX1 had a mixed trophic structure, with 43% of animals belonging to multiple groups, 29% to shredders and 21% to collectors
- UCHAP5 had the highest proportion of predators of all sites (57%).

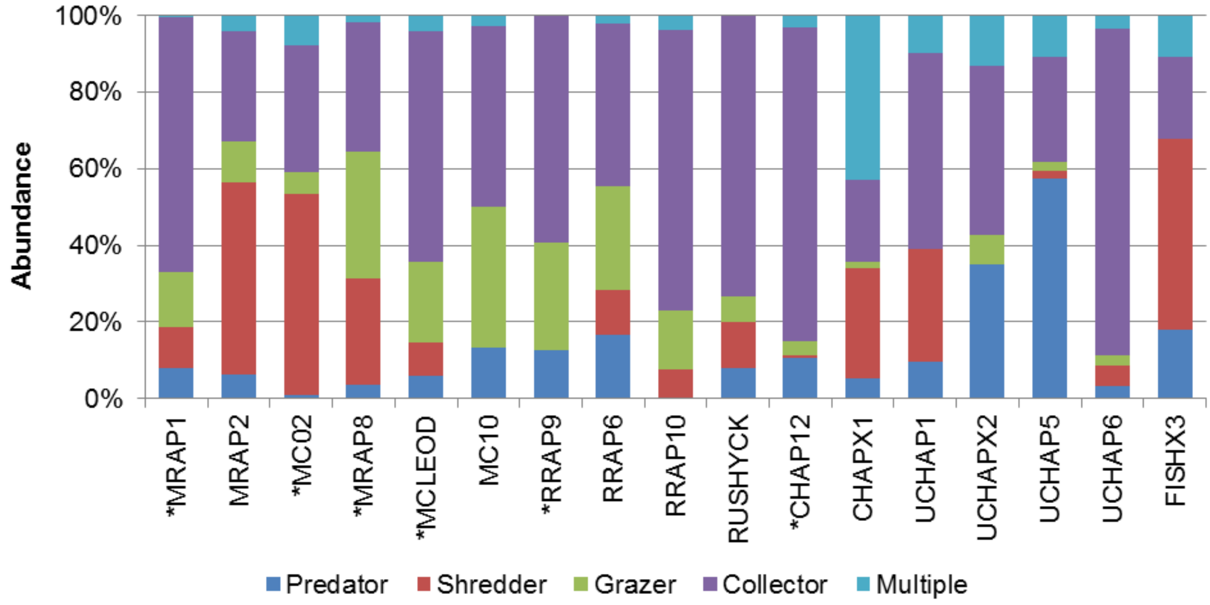


Figure 43 Proportional abundance of macroinvertebrates by functional feeding group by site, October 2012

*Note: * abundance was estimated from the sub-sample (see Section 3.4.6).*

4.6.2 Sub-theme: fish and crayfish

Due to insufficient water, fish sampling was not conducted at:

- UCHAP1 in October 2012
- MC02, CHAP12, CHAPX1, UCHAP1, UCHAP6 or FISHX3 in February 2013.

Species richness

Sixteen fish and crayfish species, including three non-natives, were collected within the study area during the October 2012 and February 2013 sampling events.

The species assemblage comprised (for common names, see the Species list following the Glossary):

- five freshwater fish (*Galaxias occidentalis, Galaxiella munda*[8], *Nannoperca vittata, Bostockia porosa, Tandanus bostocki*), all endemic to south-west Western Australia
- four native fish known to move between marine and freshwater environments (*Afurcagobius suppositus, Psuedogobius olorum, Leptatherina wallacei, Geotria australis*[9]*),* two of which are endemic to south-west Western Australia (*A. suppositus, L. wallacei*)

[8] Listed as a Threatened species under the *Wildlife Conservation Act 1950* (DPaW 2013).

[9] Listed as a Priority 1 (poorly known) species by DPaW (2013).

- four native freshwater crayfish (*Cherax cainii, Cherax crassimanus, Cherax preissi, Cherax quinquecarinatus*) endemic to south-west Western Australia
- two exotic fish (*Gambusia holbrooki, Phalloceros caudimaculatus*) and one exotic freshwater crayfish (yabby, *Cherax* spp.).

The number of native species present in October 2012 at any one site ranged between two and nine species (Figure 44), with typically fewer species in the upper catchment sites (MRAP1, MRAP2, RRAP6, CHAP12, UCHAP1). The highest native species richness was seen in the lower catchment sites in the McLeod Creek system (MCLEOD and MC10).

At the sites assessed in February 2013 (MC10, UCHAPX2 and UCHAP5), species richness was different compared with that found in October 2012 (Figure 45). Compositional differences are discussed later in this section.

Additional observations

A large number of cormorants (more than 100) were observed around the large farm dam on the Rushy Creek in February 2013.

Seven *Chelodina oblonga*[10] (long-necked tortoise) were found at site MC10 in the lower McLeod Creek in February 2013. In addition, a school of *Acanthopagrus butcheri* (black bream) were observed at this site, and there was a possible sighting of a *Hydromys chrysogaster*[11] (water rat) on the bank.

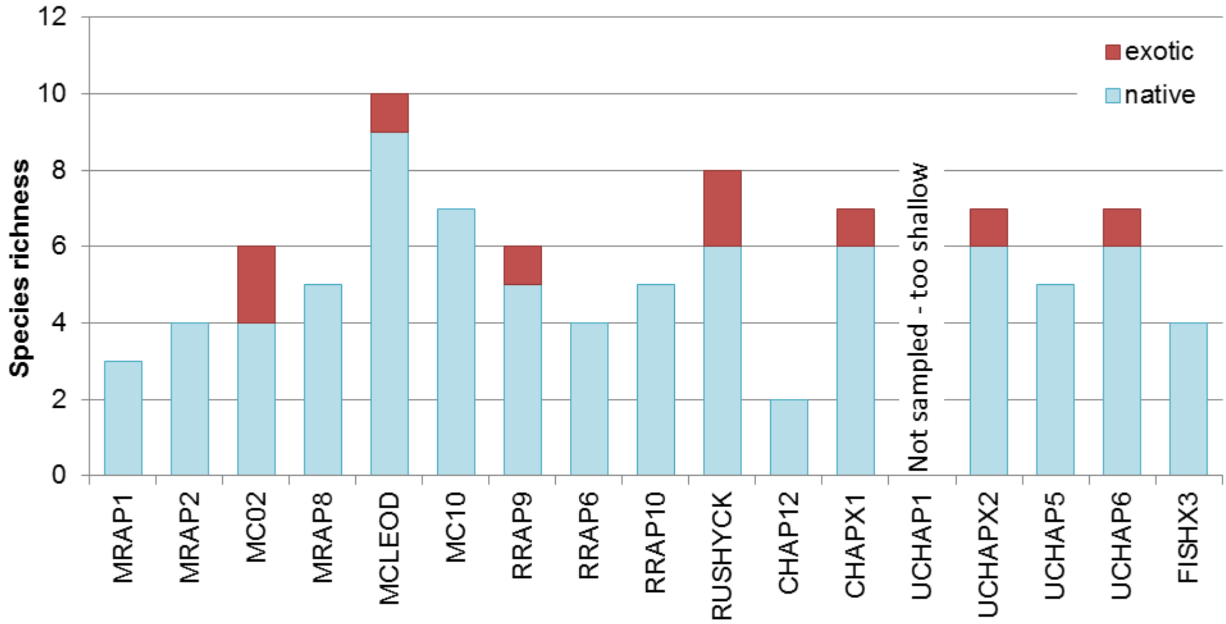


Figure 44 Fish and crayfish species richness by site, October 2012

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[10] Listed as a Near Threatened species (IUCN 1996).

[11] Listed as Priority 4 by DPaW (2013).

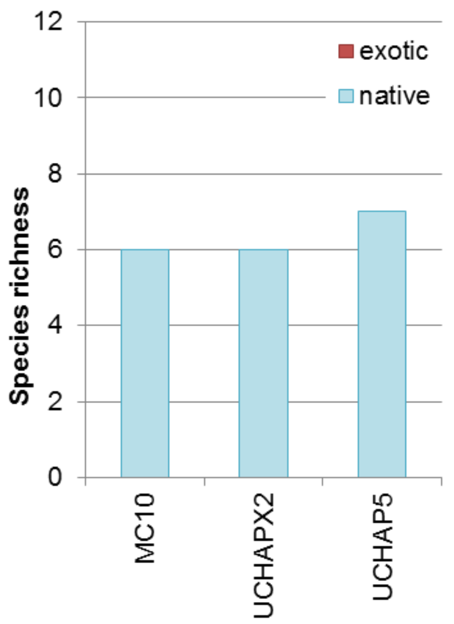


Figure 45 Fish and crayfish species richness by site, February 2013

Species distribution

The distribution of species collected in October 2012 varied considerably across the study area. A distribution map for each species is provided in Appendix S and general patterns highlighted in Table 40. In summary:

- *C. quiquecarinatus, G. occidentalis* and *N. vittata* were found at almost all sites
- *P. olorum, A. suppositus* and *T. bostocki* were largely restricted to the lower catchment of the McLeod Creek system
- *G. munda* were found in three tributary systems: at three sites (upper, mid and lower catchment) in McLeod Creek, in the mid catchment of Upper Chapman Brook and in the site at the lower end of Fisher Creek
- *C. cainii, B. porosa* and *C. crassimanus* were found in multiple sites but with no clear pattern relating to system or place in catchment, although they were absent from the upper catchment sites in some systems
- *C. preissii* were only found at site FISHX3
- *P. caudimaculatus* were found only at site MC02
- Yabby (*Cherax* spp.) were found at two sites in the Rushy Creek (RRAP9 and RUSHYCK) and one site in the Upper Chapman Brook (UCHAPX2)
- *G. holbrooki* were found at five sites: MC02, MCLEOD, RUSHYCK, CHAPX1 and UCHAP6.

At the sites sampled in February 2013 (MC10, UCHAPX2 and UCHAP5), several changes in fish assemblages between sampling events were apparent, which were (Table 41):

- *G. munda* and *G. australis* were detected at UCHAP5 in February 2013 (these species were not found at this site in October 2012; the latter was not previously seen at any site in October 2012)
- *G. occidentalis*, *C. crassimanus* and *C. quinquecarinatus* were replaced with *B. porosa* and *L. wallacei* at site MC10 in February 2013
- yabby (*Cherax* spp.) were not detected at UCHAPX2 in February 2013 (previously found in October 2012).

Table 40 Distribution of fish and crayfish species by site, October 2012 (listed by distance from Blackwood River)

		Native fish – freshwater					***Native fish – freshwater with marine affinities***				***Native crayfish – freshwater***				***Exotic fish and crayfish***		
	Approximate distance from Blackwood River (km) (Figure 45)	***G. occidentalis***	***G. munda***	***N. vittata***	***B. porosa***	***T. bostocki***	***P. olorum***	***A. suppositus***	***L. wallacei***	***G. australis***	***C. cainii***	***C. quinquecarinatus***	***C. crassimanus***	***C. preissi***	***G. holbrooki***	***P. caudimaculatus***	**Yabby (*Cherax* spp.)**
'abundant' threshold		>40	>20	>40	>20	>20	>40	>40	>40	>20	>20	>20	>20	>20	>20	>20	>20
MC10 ***	1	X		**XX**			X	X			X	**XX**	X				
MCLEOD ***	2	**XX**	X	X	X	X	X				X	X	X		X		
RUSHYCK ****	2	**XX**		**XX**	X		**XX**				X	X			X		X
FISHX3*	2		X									**XX**	X	X			
RRAP10 ****	3	**XX**		X			X				X	**XX**					
RRAP6 ****	3	**XX**		X							X	X					
CHAPX1 *	3.5	**XX**		X	X						X	**XX**	X		X		X
RRAP9 ****	7.5	**XX**		**XX**								**XX**	X				
UCHAP6 *	9.5	**XX**	X	**XX**	X						X	**XX**			X		
MRAP8 *	10	X	X	X	X							X	X				
MC02 *	10	X	X	X								**XX**			**XX**	X	
UCHAPX2 ***	12	**XX**		**XX**	X						X	X	X				X
UCHAP5 ***	14	X		**XX**	X						X	**XX**					
MRAP2 *	15	**XX**		X							**XX**	X					
CHAP12 *	15	X										**XX**					
MRAP1	17.5	**XX**	X									X					
UCHAP1 **	18.5	Dry															

** dry in February 2013, ** dry in October 2012, *** wet in February 2013, *** wet in October 2012 – unknown for February 2013*

Species present = X, abundant = ***XX***

Table 41 Distribution of fish and crayfish species by site, February 2013

		Native fish – freshwater					***Native fish – freshwater with marine affinities***				***Native crayfish – freshwater***				***Exotic fish and crayfish***		
	Approximate distance from Blackwood River (km) (Figure 45)	***G. occidentalis***	***G. munda***	***N. vittata***	***B. porosa***	***T. bostocki***	***P. olorum***	***A. suppositus***	***L. wallacei***	***G. australis***	***C. cainii***	***C. quinquecarinatus***	***C. crassimanus***	***C. preissi***	***G. holbrooki***	***P. caudimaculatus***	**Yabby (*Cherax spp.*)**
'abundant' threshold		>40	>20	>40	>20	>20	>40	>40	>40	>20	>20	>20	>20	>20	>20	>20	>20
MC10				**XX**	X		X	**XX**	**XX**		X						
UCHAP5 ***		X	X	X	X					X		X	X				
UCHAPX2 ***		**XX**		**XX**	X						X	X	X				

** dry in February 2013, ** dry in October 2012, *** wet in February 2013, *** wet in October 2012 – unknown for February 2013*

Species present = X, abundant = ***XX***

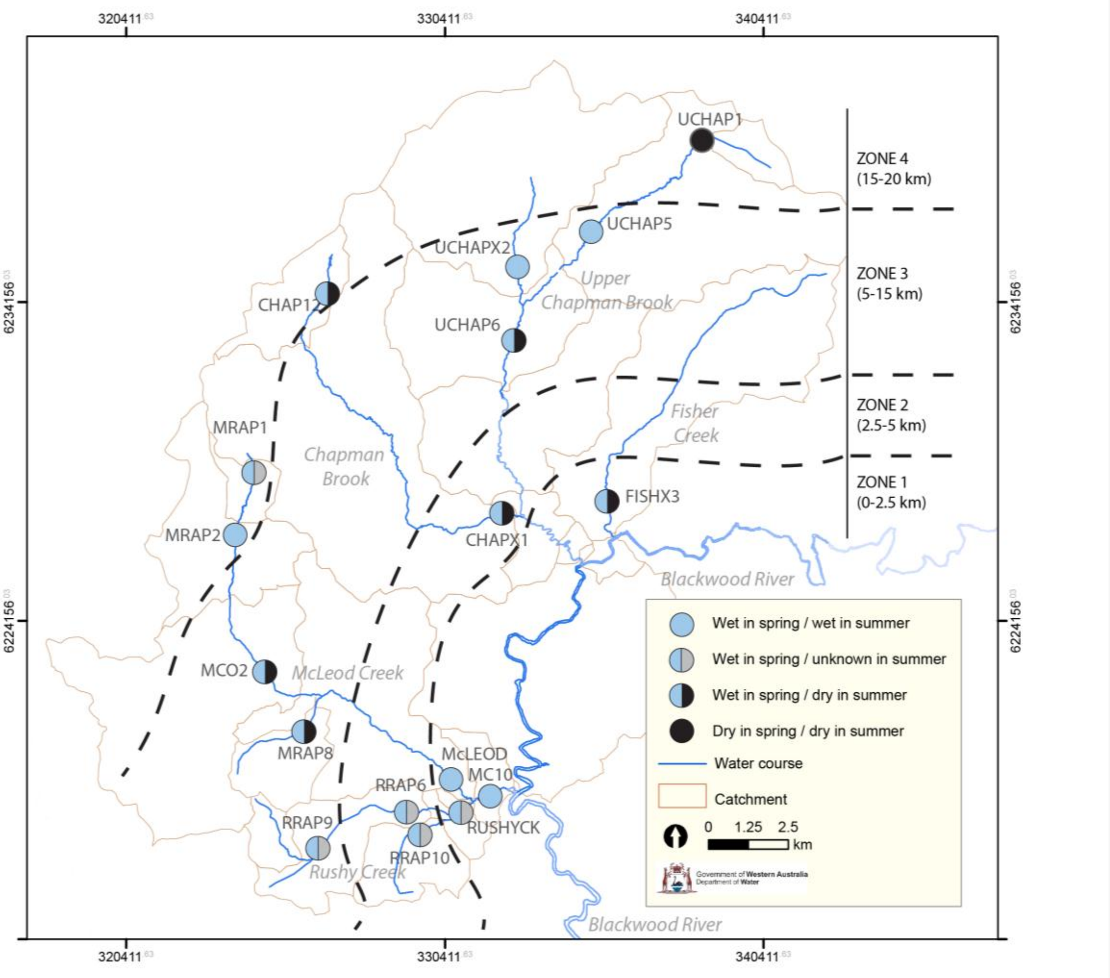


Figure 46 Approximate distance of study sites from the Blackwood River (stream length, km)

Abundance

Total abundance (Figure 47) and the abundance of each species collected in October 2012 varied at each site (Figure 48 and Appendix T).

Total abundance was highest at the Rushy Creek sites and site MC10 on McLeod Creek (immediately downstream of the confluence with Rushy Creek). This was largely due to high numbers of *G. occidentalis* and *N. vittata*. The spike in abundance recorded at the RRAP10 site was due primarily to high numbers of adult *G. occidentalis* (comprising 98% of 2159 animals recorded) (Figure 47).

G. occidentalis, N. vittata and *C. quinquecarinatus* were the dominant species at most sites (Figure 48); all other species were generally collected in low numbers.

Exotic species were absent at 10 of the 17 study sites, and no juveniles of exotic species were found. At sites where exotic species were present, they generally formed a low proportion of the total abundance; the combined abundance of *G. holbrooki,* yabby *(Cherax* spp.) and *P. caudimaculatus* did not exceed 10 individuals at any one site, with the exception of MC02, where 70 *G. holbrooki* were recorded (Figure 47).

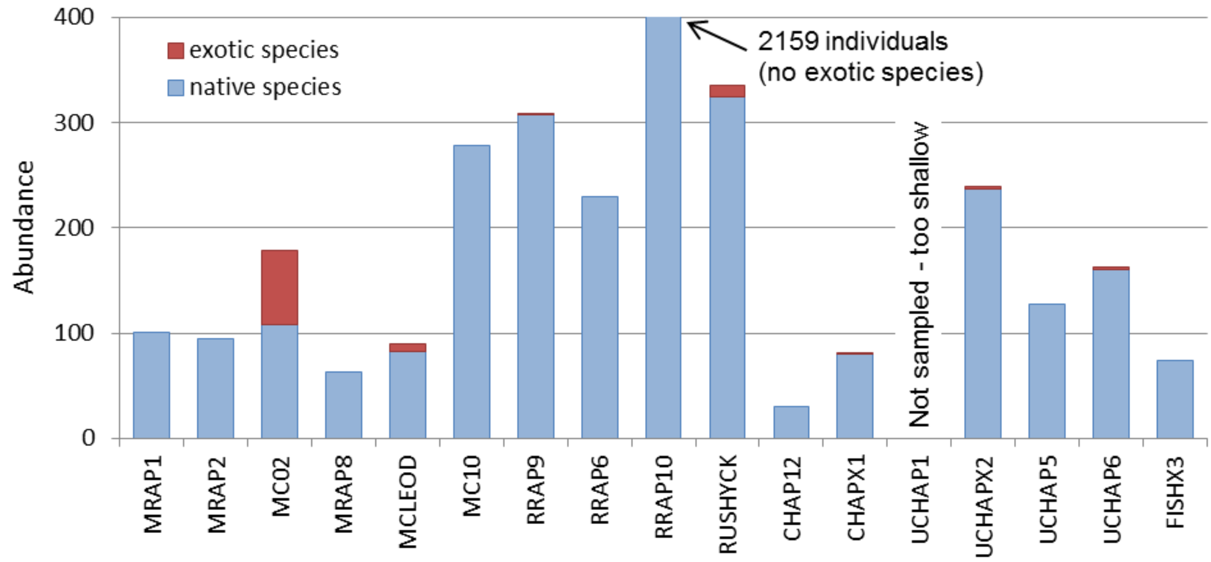


Figure 47 Total abundance of fish and crayfish by site, October 2012

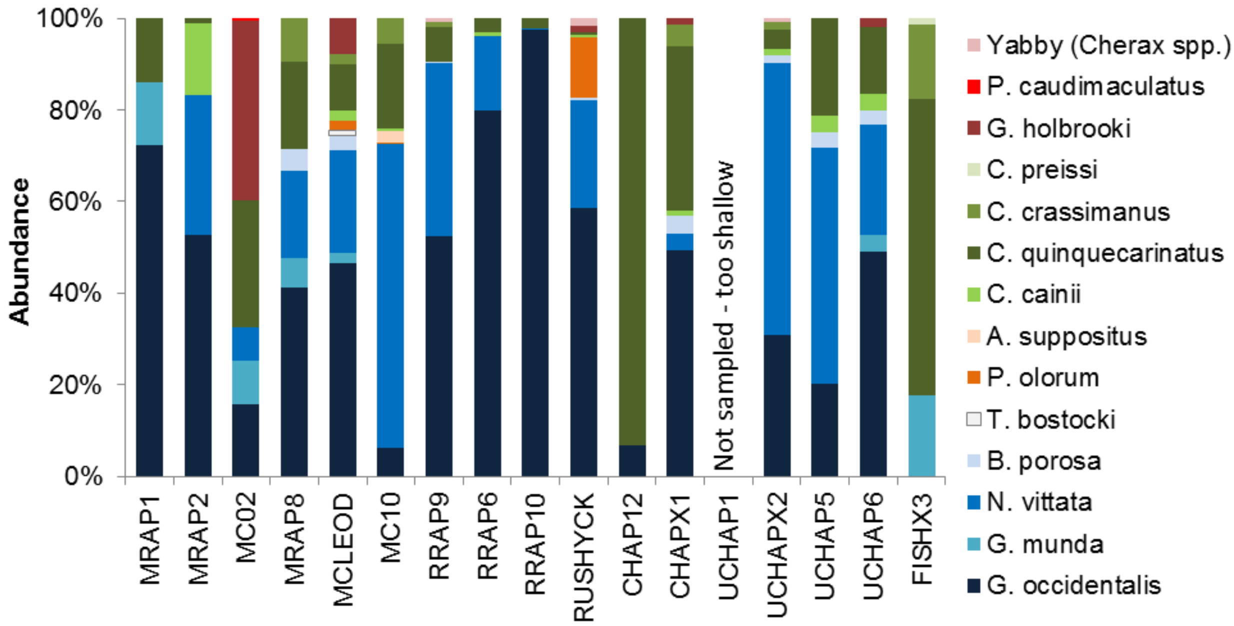


Figure 48 Composition of fish and crayfish species by site, October 2012

At the sites assessed in February 2013 (MC10, UCHAPX2 and UCHAP5), total abundance more than doubled compared with that recorded in October 2012 (Figure 49). The abundance of several species increased markedly in February 2013, namely *A. suppositus, B. porosa, N. vittata* and *L. wallacei* at MC10; *C. crassimanus, G. munda* and *G. australis* at UCHAP5; and *N. vittata* and *G. occidentalis* at UCHAPX2 (Appendix U).

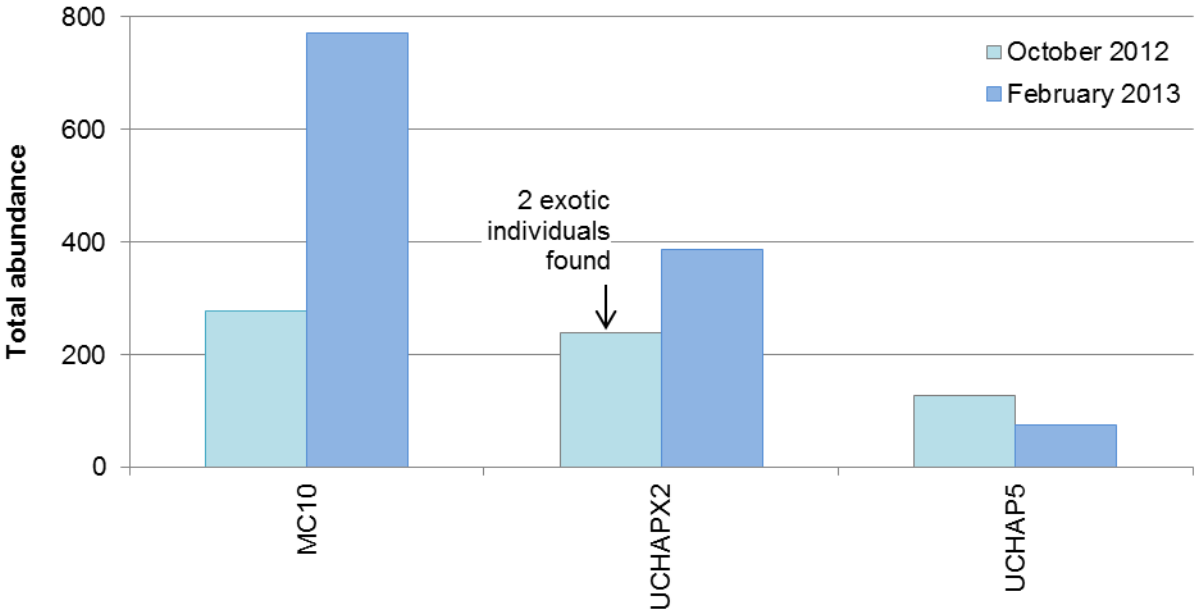


Figure 49 Total abundance of fish and crayfish at sites sampled in February 2013 compared with October 2012

Population structure

At all sites sampled in October 2012 and February 2013, the larger size classes (post-juveniles) for each species accounted for the greatest proportion of the abundance of each species (Appendix V and W); accordingly distribution of larger animals follows the general species abundance patterns previously reported. In summary, larger animals of:

- *P. olorum*, *A. suppositus*, *T. bostocki* and *C. crassimanus* were common in the lower catchment of the McLeod Creek system
- *C. preissii* were restricted to FISHX3 and *P. caudimaculatus* to MC02
- *C. cainii* and *B. porosa* were typically found towards the bottom of catchments or near sites with more permanent water (based on conditions in February 2013)
- *C. quiquecarinatus*, *G. occidentalis* and *N. vittata* were common at almost all sites.

No clear pattern was observed in the distribution of adults of the remaining species. *G. munda* and *C. crassimanus* were found in multiple sites across the study area; yabby (*Cherax* sp.) were found at two sites in the Rushy Creek (RRAP9 and RUSHYCK) and one site in the Upper Chapman Brook (UCHAPX2); and *G. holbrooki* were found at five sites (MC02, MCLEOD, RUSHYCK, CHAPX1 and UCHAP6).

Juveniles of all species were recorded with the exception of *B. porosa*, *T. bostocki* and *C. preissii.* Juveniles were found at 7 of the 15 sites in October 2012, and at all three sites sampled in February 2013 (Figure 50).

In October 2012 the following were found:

- site MC10, at the base of McLeod Creek, supported juveniles of six species: *G. occidentalis, N. vittata, P. olorum, A. suppositus, C. quinquecarinatus* and *C. crassimanus* (juvenile *A. suppositus* were not found at any other site)
- site RUSHYCK, at the base of Rushy Creek, supported juveniles of three species: *G. occidentalis, P. olorum* and *C. quinquecarinatus*
- *G. munda* and *C. crassimanus* juveniles were found at the Fisher Creek site (FISHX3); a few individuals of *G. munda* recorded at FISHX3 were around 10 mm total length, reflective of an advanced-larvae stage (yolk absent)
- the remaining sites supported juveniles of one species each: *G. occidentalis* at MRAP1, *C. cainii* at UCHAP6 and RRAP10 and *N. vittata* at RRAP9.

At the sites assessed in February 2013:

- juveniles of *N. vittata* and *A. suppositus* were again found at the MC10 site
- sites UCHAPX2 and UCHAP5 in the Upper Chapman Brook supported juveniles in February 2013 (no juveniles were recorded in October 2012 at these sites):
  - *G. occidentalis, N. vittata* and *C. quiquecarinatus* were recorded at UCHAPX2
  - *N. vittata* and *C. quiquecarinatus* juveniles were also found at UCHAP5, with *C. cainii* juveniles and *G. australis* ammocetes (no ammocetes were found at any other sites).

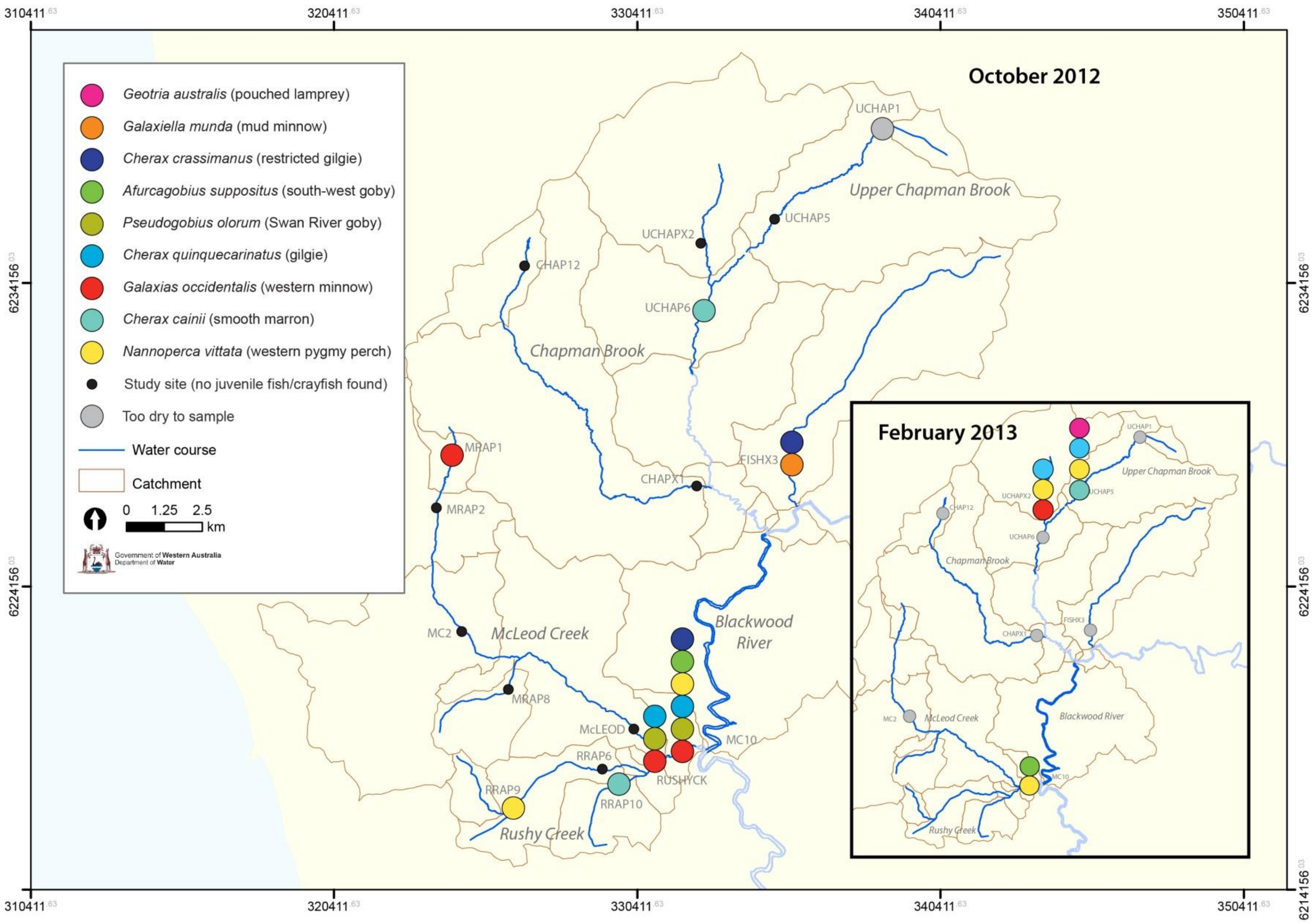


Figure 50 Presence of juvenile fish and crayfish species by site, October 2012 and February 2013

Reproductive condition

Likely gravid individuals (based on visually distended abdomens) of five fish species were recorded at several sites (Table 42). In addition, as introduced above, advanced-larvae *G. munda* were recorded at FISHX3 in October, suggesting recent spawning.

Table 42 Likely gravid individuals of native fish species found at sites, October 2012 and February 2013

		October 2012					February 2013	
River	**Site**	***G. occidentalis***	***N. vittata***	***P. olorum***	***B. porosa***	***T. bostocki***	***G. occidentalis***	***N. vittata***
McLeod Creek	MRAP1	–	–	–	–	–	n/a	n/a
	MRAP2	–	–	–	–	–	n/a	n/a
	MC02	Y	–	–	–	–	dry	dry
	MRAP8	–	–	–	–	–	n/a	n/a
	MCLEOD	Y	–	Y	Y	Y	n/a	n/a
	MC10	–	Y	–	–	–	–	–
Rushy Creek	RRAP9	–	–	–	–	–	n/a	n/a
	RRAP6	–	Y	–	–	–	n/a	n/a
	RRAP10	Y	–	–	–	–	n/a	n/a
	RUSHYCK	Y	–	–	–	–	n/a	n/a
Chapman Brook	CHAP12	–	–	–	–	–	dry	dry
	CHAPX1	Y	–	–	–	–	dry	dry
Upper Chapman Brook	UCHAP1	dry	dry	dry	dry	dry	dry	dry
	UCHAPX2	Y	–	–	Y	–	Y	Y
	UCHAP5	–	–	–	–	–	–	–
	UCHAP6	–	–	–	Y	–	dry	dry
Fisher Creek	FISHX3	–	–	–	–	–	dry	dry

4.6.3 Scores: aquatic biota index

Macroinvertebrate sub-index

The macroinvertebrate sub-index scores for all sites assessed in October 2012 ranged from 0.16 to 0.91, with sites in all five SWIRC condition bands. The lowest scores occurred at sites MC10 (0.16) in McLeod Creek and UCHAP1 (0.18) in Upper Chapman Brook. The highest scores occurred at MCLEOD (0.91) and MRAP2 (0.82) in McLeod Creek and RRAP6 (0.86) in Rushy Creek (Figure 51).

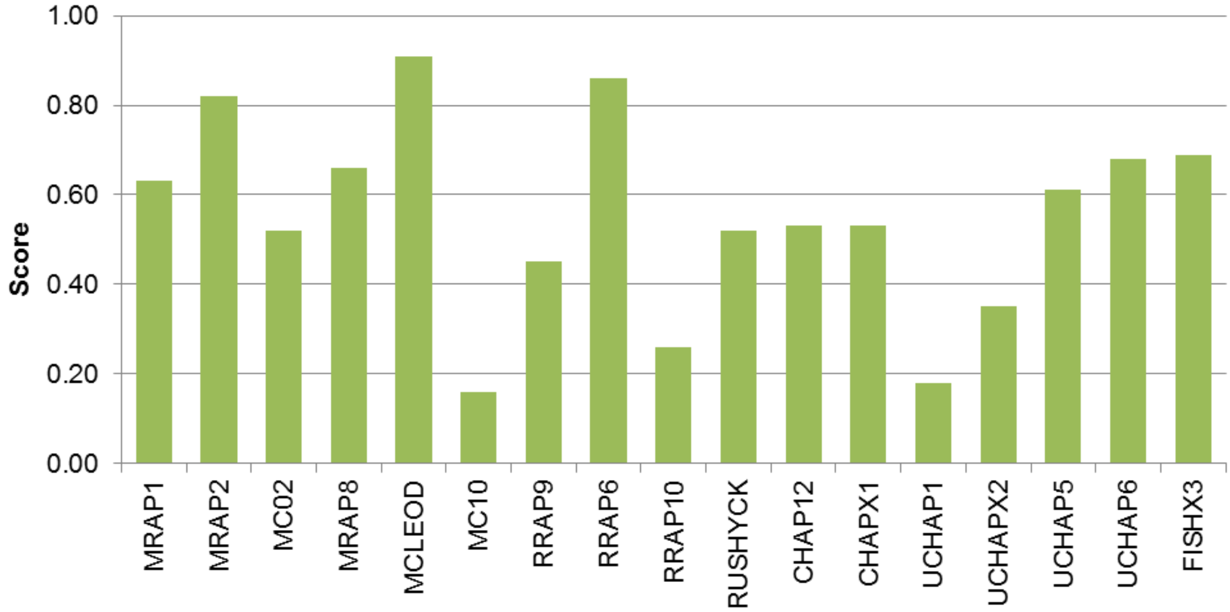


Figure 51 Macroinvertebrate sub-index scores by site, October 2012

Fish and crayfish sub-index

The fish and crayfish sub-index scores for all sites assessed in October 2012 were in the top two condition bands, with one exception (MC02) (Figure 52). This suggests that fish communities through the study area were either largely unmodified or only slightly modified from natural assemblages.

Site MC02 was the only site in the third condition band, suggesting a moderate level of modification. This was due to two factors: a high proportion of the species richness and abundance comprised of exotics (two of the six species present and approximately 40% of the total abundance), and the absence of a number of expected native species.

Nativeness component scores were in the top condition band for all sites except MC02.

Expectedness component scores were in the top two condition bands and for all sites except MC02, RRAP6 and RRAP9 (moderately modified) and CHAP12 and MRAP2 (substantially modified).

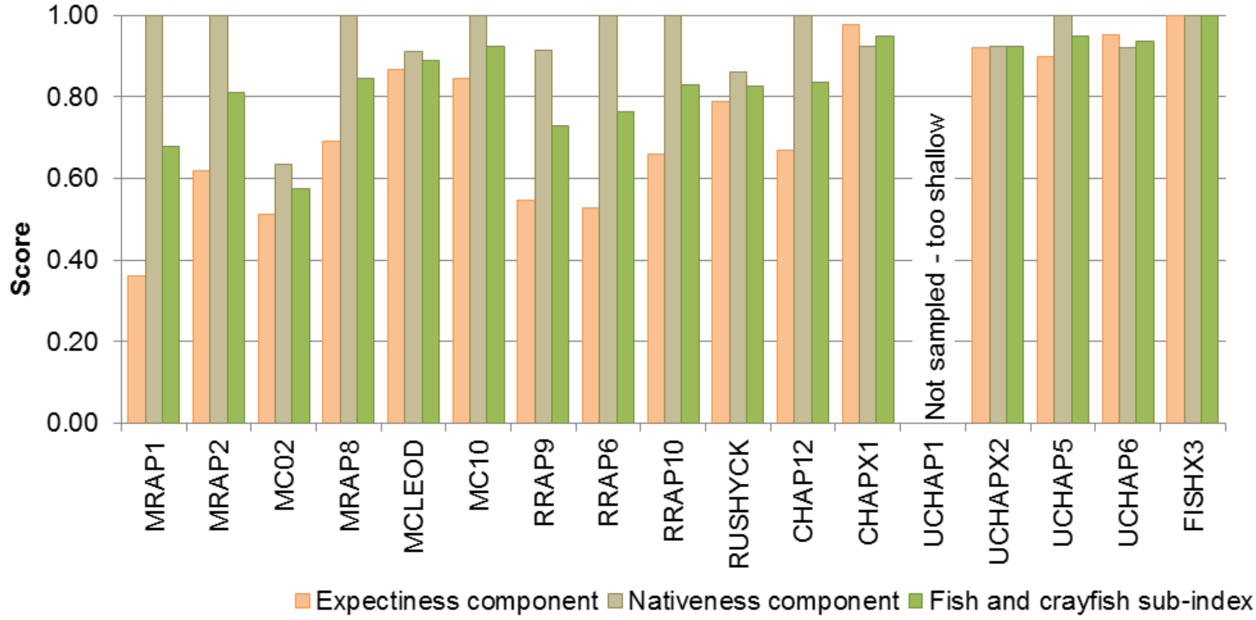


Figure 52 Fish and crayfish sub-index scores by site, October 2012

Aquatic biota index

Aquatic biota index scores for all sites assessed in October 2012 ranged between 0.18 at UCHAP1 in Upper Chapman Brook and 1.0 at FISHX3 in Fisher Creek (Figure 53). Most sites (12 of 17) were categorised in the top two condition bands (largely unmodified and slightly modified).

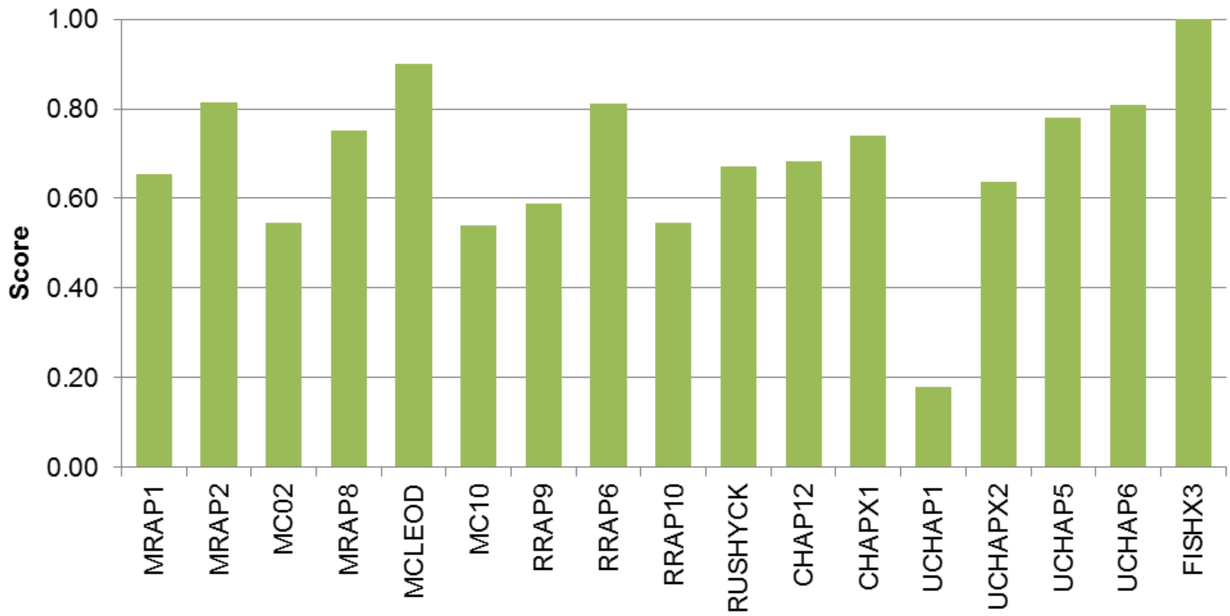


Figure 53 Aquatic biota scores by site, October 2012

Aquatic biota index scores from this study were compared with scores for 92 reaches assessed between 2008 and 2009 across south-west Western Australia (Appendix I) (data collected by Storer et al. 2011a, b). The results show the study reaches were distributed across the range of scores for reaches in the south-west. Site UCHAP1 scored lower than any other reach assessed in the south-west, while UCHAP6 in the Upper Chapman, RRAP6 in Rushy Creek and MRAP2 and MCLEOD on McLeod Creek scored in the top condition band (largely unmodified) along with 55% of the reaches assessed in the south-west.

5 Discussion

A review of the condition of each system represented by the six ecological themes assessed is presented below. Key values and potential threats identified through the condition assessment are summarised in Appendix Y, and the SWIRC scores are presented alongside scores for other river systems in south-west Western Australia in Appendix I.

5.1 McLeod Creek

Based on the SWIRC scores, McLeod Creek was generally in good condition, with the majority of the ecological index scores across the six reaches being categorised as largely unmodified or slightly modified (top two condition bands), and the remainder being moderately modified (Figure 54).

At the sub-index and component level, there was a small degree of variability in condition, with the upper reach (MRAP1) and the lower reach (MC10) showing substantial to severe modification within some of the ecological sub-themes.

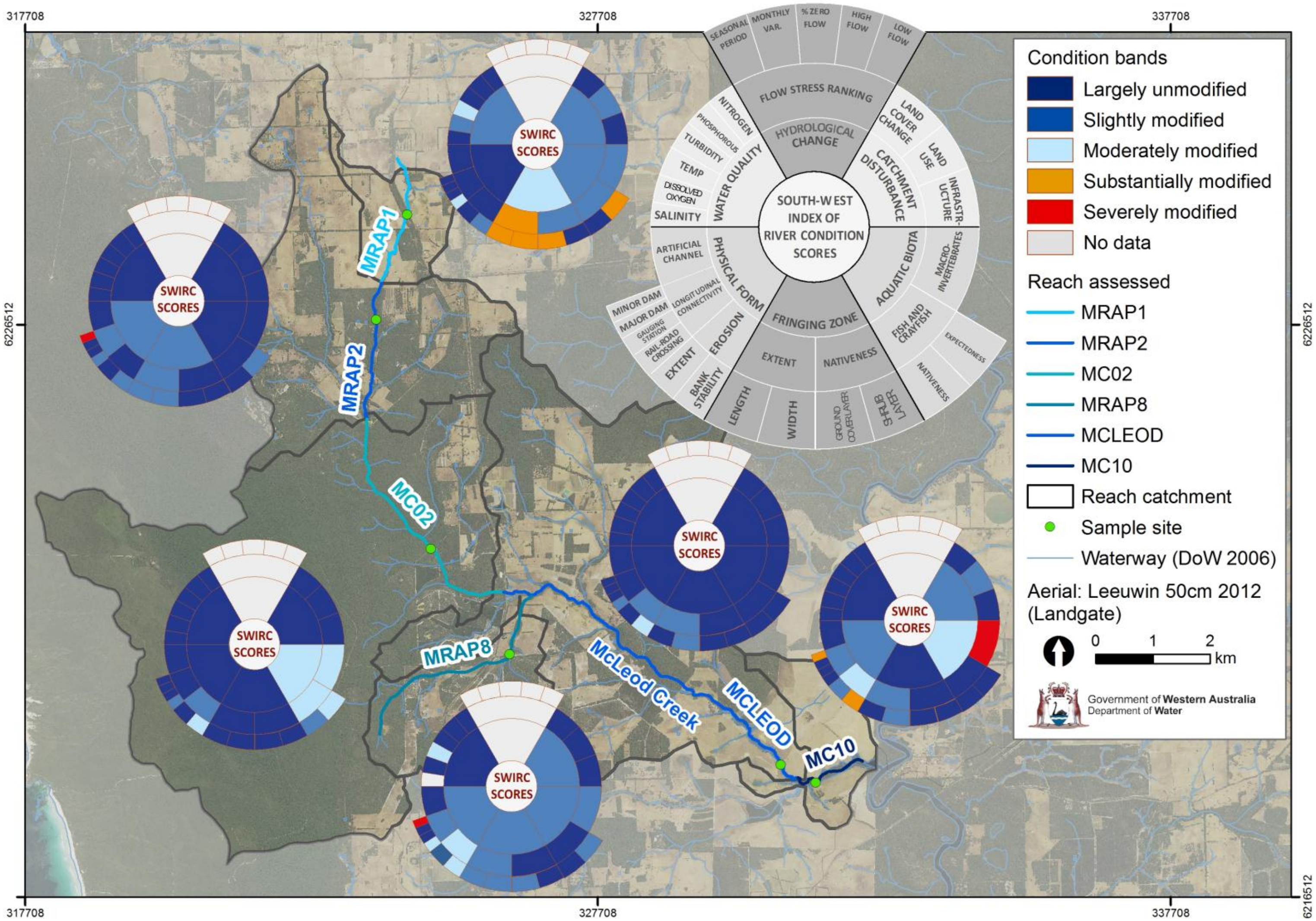


Figure 54 SWIRC scores for McLeod Creek reaches (October 2012 assessment)

5.1.1 Theme: catchment disturbance

Based on 2007 land use data, the catchment of McLeod Creek was characterised by conservation/minimal use (63%) concentrated in the mid catchment (Leeuwin-Naturaliste National Park), with some smaller areas in the upper and lower catchment. Grazing covered 29% of the catchment, and the remainder was used for plantation forestry (6%) and intensive uses (3%). The dominance of these land uses varied across the six reach catchments assessed, however the land use sub-index scores for all six reach catchments were in the top two condition bands (largely unmodified to moderately unmodified).

The loss or gain of perennial vegetation between 2007 and 2011 varied across the six reach catchments, with the greatest loss (11% of the area) occurring in the catchment for reach MRAP8. In the remaining five reach catchments, a small proportion of vegetation was lost (maximum 2% of the area) in all except MC02, where a gain of 1% occurred. The land cover change sub-index scores were in the top condition band (largely unmodified).

The proportion of each reach catchment covered by infrastructure was low (between 0.3 and 1.6%), consequently the infrastructure sub-index scores were in the top condition band (largely unmodified) for all six reach catchments.

When the three sub-index scores were integrated, the resulting catchment disturbance index scores for all six reach catchments were in the top two condition bands (largely unmodified to slightly modified).

5.1.2 Theme: hydrological change

Sub-theme: flow stress ranking

The flow stress ranking sub-index was not calculated for McLeod Creek due to insufficient flow data.

Sub-theme: farm dams

McLeod Creek had a farm dam density of 8 ML/km^2 and development of 4.3%, indicating that approximately 4% of the mean annual flow for the catchment can be held within farm dams.

Aside from Fisher Creek, McLeod Creek catchment had the lowest farm dam density and development of the catchments assessed, indicating that it experiences less modification to flow via farm dams than other catchments in the study area.

The farm dam density and development for McLeod Creek falls within the lower end of the range calculated for a selection of catchments in south-west Western Australia, which showed a density of between 2 and 27 ML/km^2 and development between 1 and 17% of mean annual flow (SKM 2009).

Supplementary information – observations of permanent water

All sites sampled in June and October 2012 were flowing, however in February 2013, water was only observed at one excavation/soak in the upper catchment, and in the lower catchment.

Upper to mid catchment

In the upper catchment, site MRAP2 was completely dry in February 2013, however a pool was observed at the downstream end of the site. This is a constructed excavation/soak that is thought to intersect the groundwater table (Julian Woodward pers. comm. 2013). A surface water abstraction licence is current at this location (Department of Water, Water Resource Licensing database). Fish and crayfish were observed in the pool in February 2013 suggesting it pool provides a permanent water refuge for aquatic biota (see fish and crayfish sub-theme).

During field surveys for the McLeod and Rushy Creek river action plan (Janike & Janike 2013), a large farm dam was identified in the upper catchment of McLeod Creek, approximately 0.1 km downstream of site MRAP2. This may provide a permanent water refuge for biota during summer.

Sites MC02, MRAP8 and one observation location (Bussell Highway) in the mid catchment were dry. This is consistent with the observations of Janike & Janike (2013) that stream flows in McLeod Creek had ceased or were minimal upstream of Bussell Highway in December 2012.

Lower catchment

In the lower catchment in February 2013, water at site MC10 was approximately 1 m to 1.5 m deep (compared with >2 m deep in October 2012). There was no visible evidence of flow, and the flow rate was below the detection limit of the flow meter. The presence of water at this site and the increase in abundance of fish and crayfish in February 2013 compared with October 2012, suggests the site was being used as a refuge by aquatic biota during the sampling period (see fish and crayfish sub-theme). This agrees with Beatty et al. (2008) who suggested the creek was a refuge for freshwater species from the tidally influenced waters of the Blackwood River.

In December 2012, Janike & Janike (2013) observed that flow in McLeod Creek increased substantially approximately 2.5 km downstream of Bussell Highway (despite having ceased upstream of the highway), which they suggest is due to groundwater input. This observation is in the region of the boundary between the fractured rock aquifers of the Leeuwin Zone and the sedimentary aquifers of the Perth Basin (see Section 2.3).

Three pools were identified by Janike & Janike (2013) on the lower reach of McLeod Creek (approximately 2.5 km upstream of the MCLEOD site) during field surveys in October 2012. Further observations at a greater temporal scale would be required to determine the duration and quality of these potential refugia during the summer months.

5.1.3 Theme: fringing zone

Based on the fringing vegetation index scores, the fringing zone of McLeod Creek was largely unmodified to slightly modified. The main exception to this was the uppermost reach, MRAP1, where the fringing zone was categorised as moderately modified.

Upper catchment – MRAP1 and MRAP2

On reach MRAP1, in the upper catchment, the extent of fringing vegetation was considerably reduced compared with elsewhere in the system, with only 29% of the length covered by vegetation, and an average vegetated width of 11 m on each bank. The ground cover layer at site MRAP1 comprised 50 to 75% exotic species, although exotics were not observed in the shrub layer. The site was located in a narrow pocket of remnant vegetation in a road reserve, but immediately upstream the creek ran through open grass paddock with no visible fringing zone vegetation – which is likely to enable the invasion of exotic ground cover species into the remnant vegetation.

By contrast, reach MRAP2 (immediately downstream of MRAP1) had a greater extent of fringing vegetation (76% of the reach length vegetated, and an average width of 34 m on each bank. The proportion of exotic species found was low (1–10% in ground cover and shrub layers).

Mid catchment and southern tributary – MC02 and MRAP8

Reach MC02 had a high extent of fringing vegetation, with 98% of the reach length covered, and an average width of 49 m (on both banks). Note: a maximum width of 50 m was assessed for this study, however the average width is likely to be much greater given the majority of the reach catchment is reserved for conservation/minimal use. The proportion of exotic species found at site MC02 was low (1–10% in ground cover and shrub layers).

Reach MRAP8 also had a high extent of fringing vegetation (78% length, 34 m average width on both banks). The proportion of exotic species at site MRAP8 was higher than at MC02, with 10–50% of the ground cover layer comprising exotic species.

Lower catchment – MCLEOD and MC10

In the lower catchment the fringing vegetation was more intact than in the upper catchment, with 85% of the length of reaches MC10 and MCLEOD covered by vegetation, and an average width of 36 m of vegetation on each bank.

At site MCLEOD the vegetation cover within the first 10 m from the waterline was dense (50–75% ground cover, 75–100% cover of shrubs), and included scattered trees within the first 10 m of the bank. Exotic species were observed in the ground cover layer but in low proportion (1–10%) compared to the native species, and were limited to the downstream end of the site, primarily alongside the track that crosses the creek at this location.

At site MC10, the vegetation cover was dense in the ground cover and shrub layers (75–100% cover in each layer) with no exotic species observed. While trees were absent within the first 10 m of the bank, they were present at other sites in the catchment, suggesting the tree layer along the creek line may have been cleared in the past. Alternatively, this may reflect the natural vegetation structure for the creek at the base of the catchment, where the channel is wider and deeper than further upstream. The intactness of the ground and shrub vegetation (high proportion of cover, no exotic species) can most likely be attributed to on-ground management, with the river corridor along the whole length of this reach being fenced to prevent stock access.

5.1.4 Theme: physical form

Based on the physical form index scores, the reaches assessed in McLeod Creek were in the top two condition bands (largely unmodified and slightly modified).

The extent of erosion at all six sites was low (0 to 20% of the site length).

In the upper and mid catchments, sites MRAP1, MRAP2 and MC02 had both moderate and dense cover of shrubs and trees (between 10 and 100% provided by each layer) within the first 10 m of the water's edge. Given the root structures of riparian vegetation can bind bank sediments together and absorb the force of flowing water (Pen 1999; Abernethy & Rutherfurd 1999), the moderate to dense vegetation cover may provide the banks with protection from erosion.

In the southern tributary (MRAP8) and lower catchment (MCLEOD and MC10), the sites had a dense cover of shrubs (75–100%). Trees were absent from MC10 (see fringing zone theme). MRAP8 and MCLEOD had a sparse cover (1–10%) of small trees (<10 m tall), and taller trees (>10 m tall) were absent. Given the sediment binding and force absorption functions can be lost if vegetation is cleared or becomes degraded (Rutherfurd & Ducatel 1994, cited in Pen 1999), the sparse tree cover may leave these sites vulnerable to future erosion.

Using the erosion sub-index, the site scores were categorised in the top three condition bands (largely unmodified to slightly modified).

One potential minor dam was identified on reach MRAP2, along with two on reach MRAP8. Several road crossing points were also identified throughout the catchment. Ground-truthing of these potential barriers is recommended to confirm the presence of any structures, and the extent to which they may prevent biota movement. Given the potential presence of barriers, the longitudinal connectivity sub-index scores indicated these reaches were slightly modified.

5.1.5 Theme: water quality

Water quality parameters were generally within guidelines. Of the samples that exceeded guidelines, only two were collected in October 2012 (at MRAP1), and hence are the only aspects captured by the water quality index and sub-indices. Using the water quality index, all sites were categorised in the top two condition bands (largely unmodified and slightly modified).

Upper catchment – MRAP1

At site MRAP1, in the upper catchment of McLeod Creek, diel dissolved oxygen recorded in October 2012 was below the guideline (5 mg/L, Koehn & O'Connor 1990) for 12 hours, with a minimum concentration of 2.8 mg/L. The maximum concentration was 11.1 mg/L, giving a range of 8.4 mg/L, which was the greatest range recorded in the study.

The diel temperature range of 13 °C exceeded the guideline of 4°C (Storer et al. 2011b). The maximum temperature of 26 °C was uncharacteristically high for the region, with the mean maximum temperature of all sites in October 2012 being 19 °C (± 3 °C). The high maximum temperature and large diurnal range are likely due to the shallow water depth and lack of shading in the paddock upstream resulting in warm water flowing into the site).

Mid catchment – MC02

At site MC02, the total nitrogen concentration of 2.1 mg/L measured in June 2012 was slightly above the guideline of 1.2 mg/L (ANZECC & ARMCANZ 2000a). Total oxidised nitrogen (nitrate and nitrite) was the dominant species, accounting for 93% of the total nitrogen in this sample. Elevated nitrate, a major component of total oxidised nitrogen, is consistent with the use of inorganic fertilisers (Mason 1991). This finding is interesting given the site is located within a reach catchment dominated by conservation/minimal land use (91% of the area) – suggesting that fertiliser application in the catchment would be limited. Further investigation at a greater spatio-temporal scale is required to determine the seasonal variability in concentrations and the source.

Lower catchment – MC10 and MCLEOD

At site MC10, the total nitrogen concentration in June 2012 (1.4 mg/L) and February 2013 (3.3 mg/L) exceeded the guideline of 1.2 mg/L (ANZECC & ARMCANZ 2000a). Note: the concentration measured in October 2012 was below guideline (0.7 mg/L). Total oxidised nitrogen (nitrate and nitrite) was the dominant species, accounting for more than 75% of the total nitrogen in both June 2012 and February 2013. As discussed above, nitrate is a major component of inorganic fertilisers, which may suggest the total oxidised nitrogen is derived from fertiliser application to the grazing land in the catchment (for fertiliser application rates on grazing land in the nearby Scott River catchment see Hall 2011). Further investigation at a greater spatio-temporal scale is required to determine the seasonal variability in concentrations and the source.

The electrical conductivity measured at site MC10 in February 2012 was an order of magnitude higher than in June or October 2012) (3750 µS/cm (moderately saline) compared with 428 µS/cm and 320 µS/cm respectively (fresh)). Given that the site is approximately 1.3 km upstream from the confluence of the Blackwood River, and that the tidal influence in the Blackwood River extends a considerable distance past the confluence with McLeod Creek (Hodgkin 1978), it is likely the increase in salinity at MC10 in February 2013 was caused by an intrusion of estuarine water. This is supported by Beatty et al. (2008) who found a tidal salt wedge at a site 0.5 km downstream from site MC10 (in December 2007). (Note: Beatty et al. (2008) did not observe the salt wedge at a site 0.9 km further upstream from site MC10). Further sampling at a greater spatio-temporal scale is required to determine the extent and variability of saltwater intrusion in McLeod Creek.

At the MCLEOD site, all water quality parameters were within guidelines on the one occasion it was sampled (October 2012). Compared with other data available for this site (Appendix M), the total nitrogen concentration recorded in October 2012 (0.51 mg/L) was similar to the median concentration recorded at this site during spring seasons between 2001 and 2003 (0.49 mg/L) and 2011 to 2012 (0.53 mg/L). The total phosphorus concentration recorded in October 2012 (0.007 mg/L) was lower than the median concentration for spring 2001 to 2003 (0.016 mg/L) and spring 2011 to 2012 (0.013 mg/L).

5.1.6 Theme: aquatic biota

Sub-theme: macroinvertebrates

Sixty-seven taxa were found within the McLeod Creek catchment, with sites MCLEOD and MRAP1 having the highest taxa richness of all sites in the study (39 and 26 respectively). Total abundance per site ranged from 38 to 1168 individuals.

Notable taxa collected in McLeod Creek included:

- Two new larval forms of Notoperata (caddisfly larvae) were found at three sites (MC02, MRAP8 and MCLEOD). It is unclear at this stage whether these are a new species or simply a larval form from an existing species that had not been collected previously (Rosalind St Clair pers. comm. 2013).
- *Triplectides neveipennis AV21* (caddisfly larvae) were found at two sites (MRAP2 and MCLEOD) and *Notoperata* sp. AV4 (caddisfly larvae) was found at the MCLEOD site; Sutcliffe (2003) suggests these species are endangered.
- *Riekaperla occidentalis* (stonefly) were found at MRAP8; this species is endemic to south-west Western Australia (WRM 2009).
- *Newmanuperla exigua* (stonefly) larvae were found at two sites (MRAP2 and MCLEOD). This species has Gondwanic affinities (WRM 2009). The conservation value of areas that support several Gondwanic biota are considered to be increasing as habitat is lost to development (Main 1996 cited in WRM 2009). This was the only species found during this study with Gondwanic affinities, although a previous study by CENRM (2004) found two other species in other tributaries of the lower Blackwood River: the freshwater snail *Glacidorbis occidentalis* in Milyeannup Brook and the dragonfly *Archaeosynthemis macrostigma* in Rosa Brook. Note: *Glacidorbis occidentalis* is listed as vulnerable (category D2) on the IUCN Red List of Threatened Species (IUCN 2012).
- The freshwater mussel, *Westralunio carteri*, was observed at MCLEOD. This species is listed as Priority 4 (rare, near threatened and other species in need of monitoring) by DPaW (2013).
- The introduced species *Pseudosuccinea columella* (the American ribbed fluke snail) was found at site MCLEOD (see discussion below).

In general, based on the macroinvertebrate community found, McLeod Creek was in good condition, with high taxa richness compared with other river systems in south-west Western Australia (Emma van Looij pers. comm. 2013), including a number of notable species. The presence of endemic and possibly endangered species suggests the sites sampled had limited localised disturbance to in-stream habitat. The exception was site MC10, where a low taxa richness and abundance was recorded, most likely associated with the increase in salinity observed in February 2013 (see discussion for MC10).

Using the macroinvertebrate sub-index, the sites were categorised in the top three condition bands (moderately modified to largely unmodified), with the exception of site MC10, which was categorised as severely modified.

Upper catchment – MRAP1

At MRAP1, 26 distinct taxa and a total abundance of 806 animals were found. Of the total abundance, 63% were Chironomidae and 3% were EPT taxa (Ephemeroptera: mayflies; Plecoptera: stoneflies; Trichoptera: caddisflies).

Chironomidae are thought to increase in relative abundance along a gradient of increasing nutrient enrichment or heavy metal concentration (Burton & Pitt 2002). Total nitrogen and total phosphorus were below the ANZECC & ARMCANZ (2000a) guidelines at the time the macroinvertebrate sample was taken, however the high relative abundance of Chironomidae may indicate a longer-term trend of nutrient enrichment, particularly given the creek flows into the site from a paddock with very limited riparian vegetation and stock access to the creek. Further, the genus *Tanytarsus* comprised 48% of the abundance of Chironomidae at site MRAP1. In a study on the northern jarrah forests of Western Australia, Bunn et al. (1986) found that warm water and low flow favoured Chironomidae, particularly from the genus *Tanytarsus*. The maximum water temperature of 26 °C recorded at site MRAP1 in October 2012 was uncharacteristically high for the region (see water quality theme), which may also have influenced the relative abundance of Chironomidae.

Using the macroinvertebrate sub-index scoring protocol, site MRAP1 was categorised as slightly modified, indicating that the community composition found was similar to that expected under reference conditions.

Upper catchment – MRAP2

The taxa richness and abundance at MRAP2 (20 taxa, 177 animals) was lower than at MRAP1. Chironomidae and EPT taxa were equally abundant at this site, and the trophic structure was dominated by shredders – which are generally more sensitive to environmental degradation (WRM 2009).

One species of caddisfly larvae (*T. neveipennis AV21*) described as endangered by Sutcliffe (2003) and one species of stonefly larvae (*N. exigua)* with Gondwanic affinities (WRM 2009) were found at MRAP2.

Based on the macroinvertebrate sub-index score, site MRAP2 was categorised as largely unmodified.

Mid catchment – MC02

MC02 had a taxa richness of 15 and a total abundance of 784 animals. The most notable feature of the community composition at MC02 was the apparent co-dominance of Insecta (53% of total abundance) and Crustacea (47%). In seasonally flowing south-west rivers, Insecta are typically the dominant class, accounting for around 70 to 80% of the total abundance (WRM 2007b; WRM 2011), hence this co-dominance is uncharacteristic. The Crustacea were dominated by the amphipod Chiltoniidae *Austrochiltonia* sp., an indicator of saline conditions (Bunn & Davies 1992), as well as a moderate number (48) of the silt and pollution tolerant mayfly, *Tasmanocoenis tillyardi* (WRM 2009). While total suspended solids and turbidity values were below guidelines at the time of sampling, the presence of these species suggests conditions may vary at other times of the year.

The dominant functional feeding group at this site was shredders, which are generally more sensitive to changes in water quality and in-stream habitat (WRM 2007b) however the group was almost entirely made up of the Chiltoniidae amphipod *Austrochiltonia* sp.

New larval form(s) of *Notoperata* (caddisfly larvae) were found at this site.

Using the macroinvertebrate sub-index scoring protocol, site MC02 was categorised as moderately modified, indicating the community composition found was different to that expected under reference conditions.

Southern tributary – MRAP8

At site MRAP8, on the southern tributary of McLeod Creek, 16 taxa and a total abundance of 474 animals were found. The trophic structure had almost equal representation of shredders, grazers and collectors, which is not typical of south-west Australian rivers, where forested streams are generally dominated by collectors and predators but with a high proportion of shredders (WRM 2009).

Chironomidae formed 65% of the total abundance which, as discussed previously, may suggest the occurrence of nutrient enrichment or increasing heavy metal concentration (Burton & Pitt 2002), or warm waters and low flows (Bunn et al. 1986). However total nitrogen, total phosphorus, diel dissolved oxygen and diel temperature measured at MRAP8 were within guidelines (see water quality theme), and the site was flowing (0.43 m/s). (Metals were not measured at this site in this study.)

Fifty-one *R. occidentalis* (stonefly larvae) individuals were present at this site. This species is endemic to south-west Western Australia and has a limited distribution within the region (WRM 2009).

New larval form(s) of *Notoperata* (caddisfly larvae) were found at this site.

The macroinvertebrate sub-index score indicates a slight modification to the macroinvertebrate community composition at site MRAP8.

Lower catchment – MCLEOD

Site MCLEOD had an abundance of macrophytes present. It was not possible to sample only channel habitat at this site – instead 50% channel and 50% macrophyte habitat were sampled. This may have influenced the large number of taxa and individuals found at this site, as macrophytes tend to support more macroinvertebrates than channel habitat (Kay et al. 1999).

A taxa richness of 39 and a total abundance of 1168 were recorded. The highest number of EPT taxa was found at this site (eight taxa), and the abundance of EPT taxa was the second highest in the study area. Given that EPT taxa are generally sensitive (less tolerant) to stress and often have specific habitat requirements, and that their presence often indicates undisturbed or 'healthy' streams (e.g. Barbour et al. 1999), the richness and abundance of EPT taxa may suggest this site is relatively undisturbed.

Four individuals of caddisfly larvae (*Notoperata* sp. *AV4* and *T. neveipennis AV21*), described as endangered by Sutcliffe (2003), and 48 individuals of the stonefly larvae *N.*

exigua with Gondwanic affinities (WRM 2009), were found at MCLEOD. Two new larval forms of *Notoperata* (caddisfly larvae) were found at this site.

This site was dominated by collectors, which tend to be generalists and therefore more resilient to environmental degradation (WRM 2009), however the abundance was dominated by the blackfly larvae *Austrosimulium* sp., which require relatively silt-free fast-flowing waters (MDFRC 2013).

Interestingly, MCLEOD was the only site where the introduced species *Pseudosuccinea columella* (the American ribbed fluke snail) was collected, though in low numbers (four individuals). This species is widespread through wetlands and rivers in south-west Australia, so its presence here is not unexpected. *P. columella* was not found in any other sample in this study, however this may be due to the inclusion of macrophyte habitat in this sample. Further sampling would be required to confirm the distribution of *P. columella* in the study area.

New larval form(s) of *Notoperata* (caddisfly larvae) were found at this site.

The freshwater mussel, *Westralunio carteri*, was observed at this site. This species is listed as Priority 4 (rare, near threatened and other species in need of monitoring) by DPaW (2013). While this freshwater mussel species is widespread throughout the south-west, populations are fragmented, increasing the species' vulnerability to disturbance (WRM 2011).

Based on the macroinvertebrate sub-index score, site MCLEOD was categorised as largely unmodified.

Lower catchment – MC10

At site MC10, only nine taxa were found, with a total abundance of 38. The low taxa richness and abundance, compared with other sites in McLeod Creek, may be associated with the limited in-stream habitat observed at the site, which was dominated by clay (95% cover) with very little detritus (10% cover of sparse detritus). Further, it may be associated with the variability in electrical conductivity detected in this study and by Beatty et al. (2008) (see water quality theme). Given this variability, comparison of the macroinvertebrate community at MC10 with those found at freshwater sites should be treated with caution.

Crustacea comprised 40% of the abundance, being made up of a single species – *Palaemonetes australis*. While this species is confined to south-west Western Australia, it is widespread throughout the area and can be found in large numbers in both streams and estuaries (Davis & Christidis 1997). It is tolerant of elevated salinities (though it is not truly marine) (Davis & Christidis 1997).

Collectors (47% abundance) and grazers (37% abundance) dominated the site's trophic structure. Shredders were not found which may be due to the absence of tree layers within the first 10 m of the waterline (see fringing zone theme). This leads to a lack of coarse particulate organic matter (e.g. leaves and wood) which are the main food source and habitat for shredders (Boulton & Brock 1999). This is supported by in-stream observations of sparse detritus (10% cover).

The macroinvertebrate sub-index score for site MC10 was categorised as severely modified, suggesting the community composition was different to that expected under reference conditions. This is not surprising, given the reference sites within the WA AUSRIVAS spring channel model (used to generate the sub-index score) were primarily focused on freshwater systems (Halse et al. 2001), and this site appears to be influenced by estuarine tidal waters (see water quality theme). It is not known whether the increase in salinity observed in February 2013 in this study, and in December 2007 by Beatty et al. (2008), is typical for this system or reflects drying climate conditions; as such this score should be interpreted with caution. Further sampling at a greater temporal scale is suggested to determine seasonal and annual variations in the macroinvertebrate community composition.

Sub-theme: fish and crayfish

McLeod Creek had the highest diversity of fish and crayfish of all the waterways assessed in this study, supporting 11 native species. With the exception of *G. australis* and *C. preissii*, all species present in the wider study area were found. This comprised five native freshwater fish (*G. occidentalis, N. vittata, B. porosa, T. bostocki* and *G. munda*), three native freshwater crayfish (*C. cainii, C. quinquecarinatus* and *C. crassimanus*), and three native fish known to move between marine and freshwater environments (*P. olorum*, *A. suppositus* and *L. wallacei*). Three of these species had not been recorded by previous studies in McLeod Creek (*T. bostocki, C. cainii* and *C. crassimanus*). (Note: a list of common names of fish and crayfish is provided after the Glossary).

Two exotic species (*G. holbrooki* and *P. caudimaculatus*) were found in McLeod Creek in October 2012, but limited to two sites: MC02 and MCLEOD. This was the first time *P. caudimaculatus* has been reported in the McLeod Creek. Although yabbies (*Cherax* spp.) were previously recorded in McLeod Creek's lower catchment (Beatty et al. 2008), they were not reported in this study. (Note: no exotic species were found in February 2013 at the one site sampled, MC10).

The species richness found in the lower catchment at sites MCLEOD (nine native species) and MC10 (seven native species), was high for south-west Western Australian river systems, where it is rare to find more than six native species at any one site (Storer et al. 2011b). Species richness was lower in the mid to upper catchment (between three and five species); this is not surprising given that five of the species absent in the upper catchment (*B. porosa*, *P. olorum*, *A. suppositus, L. wallacei* and *T. bostocki)* are generally associated with permanent waters, and the mid to upper catchment sites were shown to be dry during February 2013 (with the exception of one artificially deepened pool just downstream of site MRAP2, see hydrological change theme). These species have also been shown to exhibit marked seasonal variability in their distribution (see review in Morgan et al. 2011), thus may enter McLeod Creek's upper catchment at other times.

McLeod Creek was the only system where *T. bostocki, L. wallacei* and *A. suppositus* were recorded during this study, and *P. olorum* was only found in the McLeod and Rushy creek systems. McLeod Creek was the only system where *C. oblonga* (MC10, February 2013) and *P. caudimaculatus* were recorded.

The lower site on McLeod Creek, MC10, appeared to be a significant nursery, supporting juveniles of *G. occidentalis, N. vittata, A. suppositus, P. olorum, C. quiquecarinatus* and *C. crassimanus*. Juvenile *G. occidentalis* were also present in the upper catchment at site MRAP1. Larger individuals of *N. vittata* and *C. quinquecarinatus* were also more prevalent in McLeod Creek than in any other system, with *N. vittata* abundant at site MC10 and *C. quinquecarinatus* at both MC10 and MC02. A number of individuals from a range of species also appeared to be gravid (based on visual inspection), supporting the McLeod Creek system as a possible spawning habitat. During October 2012 these were *G. occidentalis, P. olorum* and *T. bostocki* at site MCLEOD, *B. porosa* at MRAP8, *N. vittata* at MC10 and MRAP2, and *G. occidentalis* at MC02.

McLeod Creek was found to be dry at a number of locations in the mid to upper reaches in February 2013, with only one permanent water refuge observed (downstream of site MRAP2, see hydrological change theme). Given the presence of several species in the top of the catchment that are known to prefer permanent water and have with limited mobility (e.g. *C. cainii*), it is likely that further refuges exist in the mid to upper catchment. A comprehensive survey of the creek is recommended.

At site MC10 in the lower catchment, the total abundance of fish and crayfish tripled from October 2012 to February 2013; this suggests that species are using the area as a summer refuge. Increases in abundance were seen in *A. suppositus*, *B. porosa*, *N. vittata* and *L. wallacei*. Interestingly, *C. quinquecarinatus* and *C. crassimanus* were common at MC10 in October 2012, but absent in February 2013. This may reflect a migration to an alternative refuge, possibly upstream, to avoid the increase in salinity (see water quality theme). The absence of the gilgie species may also be associated with predation by *C. oblonga* (long-neck tortoise) found at this site in February 2013.

The fish and crayfish sub-index scores for four sites (MCLEOD, MC10, MRAP2 and MRAP8) were high, presenting a largely unmodified condition. This reflects the lack of exotic species at these sites and the native species found being similar to expectations.

At site MRAP1 in the upper catchment, the fish and crayfish sub-index score suggested a slight modification, based largely on the absence of permanent water species (*N. vittata, B. porosa, P. olorum* and *C. cainii*). The historic data used to generate species expectations were collected from lower in the catchment, and therefore the natural range of species may not have extended to this site. Further, the site was shown to be dry in February 2013, which would explain the absence of permanent water species (especially those with marine affinities). Given the lack of historical flow data for McLeod Creek, it is unclear whether the extent and timing of drying observed in February 2013 is natural.

Site MC02, in the middle of the McLeod Creek catchment, was scored as moderately modified, and received the lowest score of all the sites assessed in this study. This was due to the absence of several native species (*B. porosa, P. olorum* and *C. cainii*) and the presence of exotic species (*G. holbrooki* and *P. caudimaculatus* comprised 40% of the total abundance, being two of the six species present). This is somewhat surprising as this site is located in a reach catchment dominated by conservation/minimal use (91%), and had the most unimpacted fringing zone of sites assessed (dense cover of vegetation in each layer;

limited exotic vegetation species). This absence of certain native species may reflect drying and proximity to refuge, however the presence of the relatively high abundance of exotic species suggests that some permanent water may exist.

5.2 Rushy Creek

Based on the SWIRC scores, Rushy Creek was generally in good condition, with over half of the five index scores for each reach being categorised in the top two condition bands (largely unmodified or slightly modified) (Figure 55). However the proportion of index scores in the top two condition bands was lower than for the other tributaries assessed (65% instead of between 74 and 100%), suggesting that Rushy Creek was in slightly poorer condition than the other tributaries.

At the sub-index and component level, a greater degree of variability in condition was apparent compared with the other tributaries assessed. Various sub-index and component scores were categorised in the bottom two condition bands (substantially modified to severely modified).

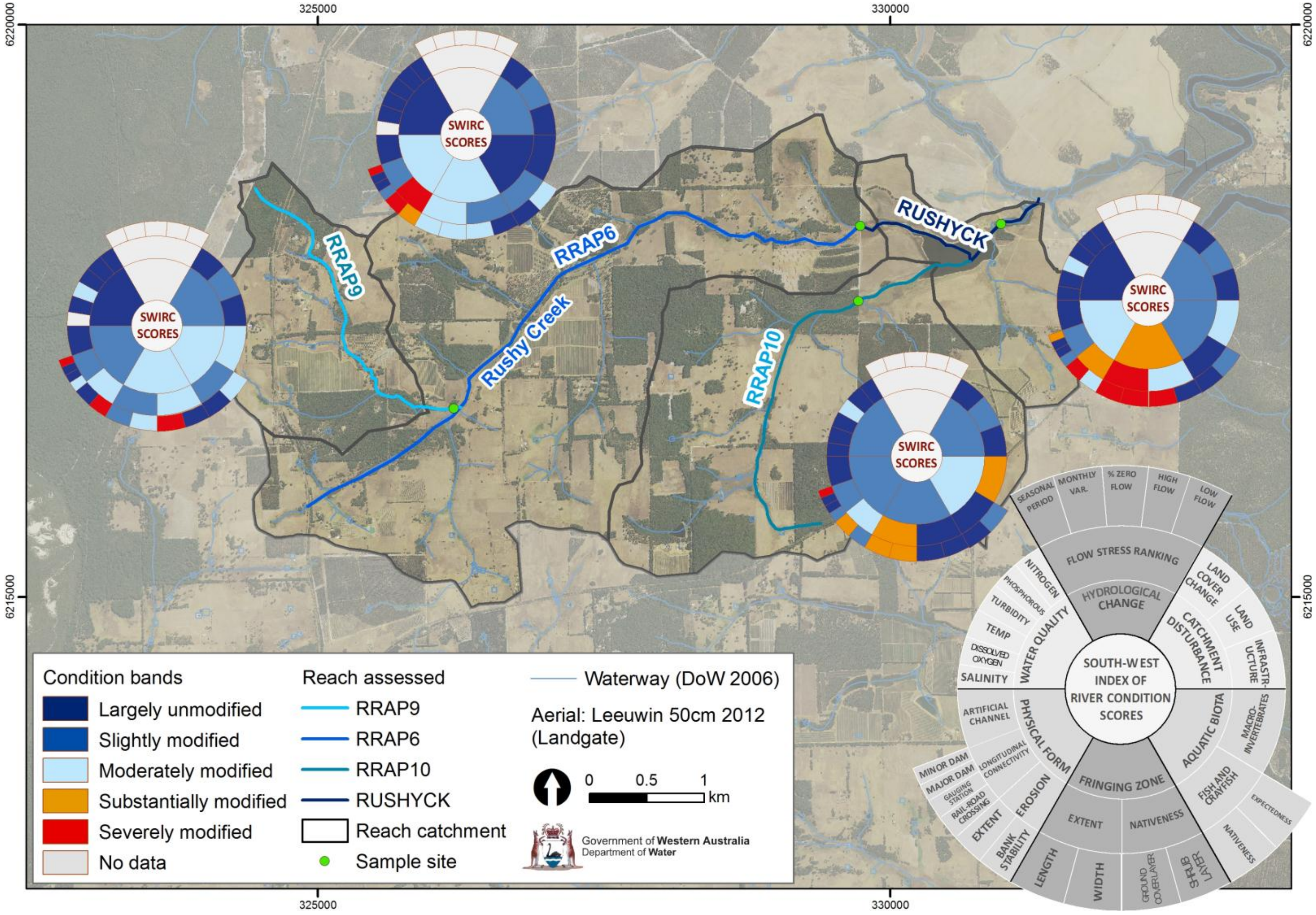


Figure 55 SWIRC scores for Rushy Creek reaches (October 2012 assessment)

5.2.1 Theme: catchment disturbance

Based on 2007 land use data, the Rushy Creek catchment had the smallest proportional area used for conservation/minimal use (25%) compared with the other tributaries assessed, and a greater proportion of land used for intensive and irrigated agriculture (12%).

Within the four reach catchments of Rushy Creek, the proportions of each land use category varied slightly, however the overall impact on river health was categorised as slightly modified using the land use sub-index scoring protocol.

The northern tributary reach catchments, RRAP9 and RRAP6, gained perennial vegetation equivalent to 3 and 1.4% of the reach catchment area respectively between 2007 and 2011. The southern tributary (RRAP10) and lower reach catchment (RUSHYCK) both lost perennial vegetation cover equivalent to 0.5% of the reach catchment area. Given these small losses, the land cover change sub-index scores were categorised as largely unmodified for all four reach catchments.

The proportion of each reach catchment covered by infrastructure was low (between 0.3 and 1.6%) – thus the infrastructure sub-index scores were in the top condition band (largely unmodified) for all four reach catchments.

When the three sub-index scores were integrated, the resulting catchment disturbance index scores for all four reach catchments were categorised as slightly modified.

5.2.2 Theme: hydrological change

Sub-theme: flow stress ranking

The flow stress ranking sub-index was not calculated for Rushy Creek due to insufficient flow data.

Sub-theme: farm dams

Rushy Creek had the highest farm dam density of the catchments assessed (39 ML/km^2). This was primarily due to the large dam in the lower catchment (upstream of site RUSHYCK). The low flow bypass channel and fish passage system, built as part of this dam, may reduce the dam's impact on the low flow portion of the flow regime in the lower reaches of Rushy and McLeod creeks. (Note: the farm dam density was recalculated without the inclusion of this dam, giving a density of 19.5 ML/km^2.)

The farm dam development for Rushy Creek was 15%, indicating that approximately 15% of the mean annual flow for the catchment can be held within farm dams. This level of development was the highest of the catchments assessed in this study, and falls within the upper end of the range calculated for a selection of catchments in south-west Western Australia, which showed development between 1 and 17% of mean annual flow (SKM 2009).

Supplementary information – observations of permanent water

Flow conditions in Rushy Creek were not assessed in February 2013 and thus it is not possible to comment on the potential permanent water refugia in the catchment – other than the large farm dam in the lower catchment. In February 2013, water was not flowing out of the dam via the spillway or bypass channel, which suggests that any flow into the dam was limited (not enough to cause flow out of the dam).

One pool and five farm dams were identified in the Rushy Creek system during field surveys for the McLeod and Rushy Creek RAP in October 2012 (Janike & Janike 2013). Further observations at a greater temporal scale would be required to determine the duration and quality of these potential refugia during the summer months.

5.2.3 Theme: fringing zone

Based on the fringing vegetation index scores, the fringing zone of Rushy Creek was slightly to moderately modified, with the exception of the lower reach, RUSHYCK, which was in a substantially modified condition.

Northern tributary and main channel – RRAP9 and RRAP6

The reaches of the northern tributary (RRAP9) and main channel of Rushy Creek(RRAP6) had a greater extent of fringing vegetation than the southern tributary and lower catchment reaches. For RRAP9, 72% of reach length was covered by fringing vegetation, with an average width of 30 m on each bank. For reach RRAP6, 59% of the length was covered, with an average width of 20 m on each bank. The fringing zone extent sub-index scores were in the slightly modified and moderately modified condition bands respectively.

Despite the higher extent of the fringing vegetation along the northern tributary, compared with other reaches in the catchment, the location selected for the RRAP9 site had very limited fringing vegetation cover (1–10% cover provided by the shrub and tree layers), with cleared paddock extending to the banks of the creek. Consequently there was a high proportion of exotic species in the ground cover layer (75–100%, primarily exotic grasses).

At RRAP6, the fringing vegetation cover within 10 m of the water's edge was primarily trees <10 m tall (10–50% cover on the left bank and 50–75% on the right), and ground cover species (50–75% cover on the left bank and 10–50% cover on the right), with a sparse shrub layer (1–10% cover on both banks). The proportion of exotic species was lower than at RRAP9, being 10 to 75% of the ground cover and 1 to 10% of the shrub layer, while none of the trees were exotic.

The nativeness sub-index scores were moderately modified for RRAP9 and slightly modified for RRAP6.

Southern tributary and lower catchment – RRAP10 and RUSHYCK

The extent of fringing vegetation was low for both reaches, with the southern tributary, RRAP10, having vegetation along 32% of the length, with an average width of 14 m on each bank. For the lower catchment reach, RUSHYCK, only 17% of the reach length was vegetated, with an average width of 6 m on each bank. The fringing zone extent sub-index scores were in the substantially modified and severely modified condition bands respectively.

At site RRAP10, the fringing vegetation cover comprised a dense layer of ground cover (50–75% cover), shrubs (75–100% cover) and trees <10 m tall (75–100% cover). Exotic species were only observed in the ground cover layer, and in low abundance (1–10% of the vegetation on the right bank, 0% on the left bank).

At site RUSHYCK, the vegetation comprised a dense layer of ground cover and shrubs (75–100% cover in each layer), but only a sparse tree layer (1–10% cover of trees <10 m tall and no trees >10 m tall). No exotic species were identified in the shrub or tree layers, but they dominated the ground cover vegetation present (75–100% of the ground cover layer). Given the presence of exotic species generally indicates disturbance (Pen 1999), this may suggest the site has been disturbed in the past. Possible disturbance factors include stock access and grazing before fence installation, or reduced flow leading to reduced inundation and subsequent establishment of weed species on the banks.

The nativeness sub-index scores were largely unmodified for RRAP10 and moderately modified for RUSHYCK.

5.2.4 Theme: physical form

The physical form index scores for Rushy Creek indicated the reaches were slightly to moderately modified.

Sub-theme: longitudinal connectivity

Based on desktop data, several potential minor dams were identified on the reaches, along with a number of road crossing points throughout the catchment. These structures may prevent the movement of biota through the creek.

Ground-truthing of the potential barriers is recommended to confirm the presence of any structures, and the extent to which they may prevent biota movement. Given the potential presence of barriers, the longitudinal connectivity sub-index scores indicated all four reaches were slightly unmodified or moderately modified.

Note: the large farm dam at the base of Rushy Creek was excluded from the list of minor dams. A fishway was installed during dam construction, and while this may have impacted on fish movement through the creek to some degree, evidence from Beatty et al. (2012) suggests this is not significant (see the fish and crayfish sub-theme for details).

Sub-theme: erosion

Northern tributary – RRAP9

At site RRAP9, the extent of erosion was minor (0–5% of the bank length), however the shrub and tree vegetation layers were sparse (1–10% cover provided by each layer). As discussed for McLeod Creek, the root structures of riparian vegetation provide a stabilising function (Rutherfurd & Ducatel 1994, cited in Pen 1999). The sparse fringing vegetation at RRAP9 may leave the banks vulnerable to future erosion. Using the erosion sub-index, the site score was categorised as moderately modified.

Lower catchment – RRAP6, RRAP10 and RUSHYCK

The extent of erosion at the three sites in the lower catchment was moderate to high: 50 to 100% of the length of sites RRAP6 and RUSHYCK, and 21 to 50% at site RRAP10.

The density of fringing vegetation cover, with its associated bank stabilisation function, varied at each site. RRAP10 had a dense cover of both shrubs and trees <10 m tall (75–100% cover of each), which may provide the banks with protection from future erosion.

At RUSHYCK, bank stability was supported by the dense shrub layer (75–100% cover), however the scarcity of trees <10 m tall (1–10 % cover), and absence of trees >10 m tall, suggests potential vulnerability to future erosion.

At RRAP6, the presence of trees <10 m tall (10–50% cover on the left bank and 50–75% on the right) provides the banks with some stabilising function, however the sparse shrub layer (1–10% cover on both banks) and absence of trees >10 m tall increases the likelihood of further erosion.

Using the erosion sub-index, the site scores were categorised as severely modified for RRAP6, substantially modified for RUSHYCK, and moderately modified for RRAP10.

5.2.5 Theme: water quality

Using the water quality index, the sites in Rushy Creek were categorised in the top two condition bands (largely unmodified and slightly modified).

Water quality parameters were within guidelines at all four sites in October 2012 with one exception: at RRAP10 the turbidity was 27 NTU (the guideline is 10–20 NTU) (ANZECC & ARMCANZ 2000a). Given that water samples were taken on only one occasion at this site, it is not known whether the turbidity concentration is typical for the southern tributary. Further sampling is required to determine turbidity levels in this tributary.

Compared with other data available for site RUSHYCK (Appendix M), the total nitrogen concentration in October 2012, 0.81 mg/L, was slightly higher than the median concentration recorded at this site during spring seasons between 2001 and 2003 (0.57 mg/L) and slightly lower than the median concentration for spring 2011 to 2012 (0.89 mg/L). The total phosphorus concentration recorded in October 2012 (0.01 mg/L) was similar to the median concentration for spring 2001 to 2003 (0.016 mg/L) and spring 2011 to 2012 (0.013 mg/L).

5.2.6 Theme: aquatic biota

Sub-theme: macroinvertebrates

Thirty-seven taxa were found within the Rushy Creek catchment. Taxa richness at each site ranged from seven to twenty-three taxa, and total abundance per site ranged from 26 to 2522 individuals.

One notable species was found in Rushy Creek at site RRAP6 – the caddisfly larvae *T. neveipennis AV21,* described as endangered by Sutcliffe (2003).

Using the macroinvertebrate sub-index, the condition of the sites ranged from largely unmodified to substantially modified.

Northern tributary – RRAP9

Site RRAP9, on the northern tributary of Rushy Creek, had a taxa richness of 13 and the highest total abundance of any site in the study, with 2522 animals. The total abundance was dominated by Chironomidae (77%). As discussed for McLeod Creek, the dominance of Chironomidae may suggest nutrient enrichment or increased heavy metal concentration (Burton & Pitt 2002), or warm waters and low flows (Bunn et al. 1986). Although nutrient concentrations at RRAP9 at the time of macroinvertebrate sampling were below guidelines (ANZECC & ARMCANZ 2000a), evidence of livestock accessing the creek (vegetation damage and manure) was observed at the site, suggesting the possibility of nutrient inputs. The diel temperature range in October 2012 was 16 to 21 °C: the maximum temperature is warmer than the mean maximum temperature of 19 °C ± 3 °C for all sites in the study (see water quality theme), most likely due to limited shading provided by the sparse riparian vegetation present (1–10% cover of shrub and tree layers, see fringing zone theme).

The highest abundance of EPT taxa was found at this site (256 animals), however they formed only 10% of the total abundance due to the dominance of Chironomidae. Only two EPT taxa were found, including *T. tillyardi,* a mayfly that has been found at sites with higher amounts of sediment than undisturbed streams (Bunn et al. 1986) and considered to be pollution tolerant (WRM 2009). Low numbers of the blackfly larvae, *Austrosimulium* sp., were also found (26 individuals). This species needs relatively silt-free substrates to attach to (MDFRC 2013).

Collectors dominated the trophic structure at site RRAP9 (60%); grazers and predators were present but shredders were absent. Given that shredders feed on leaf litter from riparian vegetation, the absence of shredders is consistent with the lack of riparian vegetation at this site. Shredders also tend to be more sensitive than collectors to changes in habitat and water quality (WRM 2009).

The macroinvertebrate sub-index score for the northern tributary site, RRAP9, was categorised as moderately modified, indicating the community composition found was different to that expected under reference conditions.

Main channel – RRAP6

At site RRAP6, in the main channel of Rushy Creek, 23 taxa and a total abundance of 349 animals were found. Chironomidae dominated the total abundance (79%), which may indicate nutrient enrichment at this site (see discussion for RRAP9), although total nitrogen and total phosphorus were below the guidelines at the time of sampling (see water quality theme).

Four EPT taxa were present but in low abundance. One of these – *T. neveipennis AV21*, a caddisfly – was described as endangered in a study by Sutcliffe (2003).

The macroinvertebrate sub-index score for RRAP6 was categorised as largely unmodified, indicating the community composition found was similar to that expected under reference conditions.

Southern tributary – RRAP10

The taxa richness and abundance at site RRAP10 were the lowest of all the sites in the study (seven taxa and 26 animals). The only groups present were Oligochaeta, Chironomidae, Collembola and Amphipoda. These groups tend to be tolerant of poor habitat and water quality conditions (Chessman 2003; Gooderham & Tsyrlin 2002). Further, EPT taxa were absent from the site and given they are generally sensitive (less tolerant to stress) and often have specific habitat requirements (e.g. Barbour et al. 1999), this may indicate disturbance. Various in-stream habitats were observed at the site (a range of physical and biological substrate materials, varied water depths and woody debris), the streamside vegetation cover was dense (see fringing vegetation sub-theme), and the water quality parameters were within guidelines in October 2012 with the exception of slightly elevated turbidity (see water quality theme). Given these habitat and water quality conditions, further sampling at a greater temporal scale is required to determine whether the macroinvertebrate community composition found was an anomaly, or indicated a disturbance not detected during sampling.

The macroinvertebrate community was dominated by collectors, which tend to be generalists and more tolerant to environmental changes than shredders (WRM 2009). Interestingly, predators were absent from this site, which may suggest there was a low complexity of prey species present (and hence nothing for the predators to feed on). Alternatively this may be due to predation pressure by fish; in October 2012 the fish and crayfish sample included more than 2000 *G. occidentalis* at this site. Given these fish prey primarily on microcrustaceans and insects, their presence here may have contributed to the absence of predators and the very poor macroinvertebrate fauna (low richness, low abundance, simplistic community composition) (Tim Storer pers. comm. 2013).

The macroinvertebrate sub-index score of substantially modified implies the community composition was different to that expected under reference conditions. This may be due to the large number of *G. occidentalis* found at this site, however further sampling would be required to clarify the cause.

Lower catchment – RUSHYCK

At site RUSHYCK, in the lower catchment, 15 taxa and a total abundance of 164 animals were collected. The most abundant species was the blackfly larvae, *Austrosimulium* sp., which require relatively silt-free conditions (MDFRC 2013). This is supported by the observation that the mineral substrate at RUSHYCK was primarily sand, with only approximately 2% cover of silt.

The community composition was dominated by Insecta (93%), with Crustacea and Gastropoda being absent. All four functional feeding groups were present but they were dominated by collectors, which are generalists and more tolerant of environmental degradation than shredders (WRM 2009).

The macroinvertebrate sub-index score for site RUSHYCK was moderately modified, indicating the community composition found was different to that expected under reference conditions.

Sub-theme: fish and crayfish

A diverse fish and crayfish community was present in Rushy Creek with seven native species recorded within the catchment. This comprised three freshwater fish (*G. occidentalis, N. vittata* and *B. porosa*), three freshwater crayfish (*C. cainii, C. crassimanus* and *C. quinquecarinatus*) and one species known to move between marine and freshwater environments (*P. olorum*). (Note: a list of common names of fish and crayfish is provided after the Glossary).

Two exotic species were found at two sites in Rushy Creek, but in low abundance (less than five individuals per sample). The distribution of exotic species appears to have declined since the previous study of the area (Beatty et al. 2012):

- *G. holbrooki* was only found at site RUSHYCK in the lower catchment in October 2012, whereas it had previously been recorded in both tributaries.
- The yabby (*Cherax* spp.) was detected at site RUSHYCK and in the upper catchment of the northern tributary, at site RRAP9, in October 2012. It was not found in the southern tributary in October 2012, where it had previously been reported.
- *Carassius auratus* (goldfish), previously recorded in Rushy Creek below the dam, were not detected in October 2012.

These findings are encouraging because they suggest that these exotic species are not highly competitive under current conditions.

Native species richness was marginally higher at the site at the bottom of the catchment (RUSHYCK), although all species present below the large farm dam were detected across sites in the upper catchment. At RUSHYCK, the species richness of six was high for south-west Western Australian river systems, where it is rare to find more than six native species at any one site (Storer et al. 2011b).

P. olorum were only found at the bottom of the catchment (site RUSHYCK, 44 individuals) and in the southern tributary (site RRAP10, one individual). Conversely, *N. vittata* were found at all four sites during this study, with significantly high abundance in the northern tributary (site RRAP9, 117 individuals).

C. cainii and *B. porosa* were only found in low abundance within the system (maximum of two individuals per sample).

G. munda, T. bostocki and *A. suppositus* were not recorded in Rushy Creek in October 2012. Each of these species was previously reported in the system by Beatty et al. (2012), however they had only been found on one occasion (in spring 2011) and only below the dam. The absence of these species could be a function of seasonal variability.

Successful recruitment was evident for several species. The lower site on Rushy Creek (RUSHYCK) was home to juveniles of *G. occidentalis, P. olorum* and *C. quiquecarinatus*. One juvenile of *C. cainii* was found in the southern tributary at site RRAP10 and juvenile *N. vittata* were found in the northern tributary at RRAP9. Juveniles of *N. vittata, A. suppositus* and *C. crassimanus* were also common in McLeod Creek (site MC10) directly below the confluence with Rushy Creek.

Large individuals of *G. occidentalis* and *N. vittata* were abundant at all Rushy Creek sites. The southern tributary (RRAP10) appeared to be a significant habitat for *G. occidentalis,* with more than 2000 individuals collected in the 24-hour sampling period in October 2012 (over 20 times the abundance recorded at sites in other tributaries). This finding may suggest congregations for spawning. Visual observations of distended abdomens in some individual *G. occidentalis* at sites RRAP10 and RUSHYCK suggest they were gravid.

The location of permanent water refugia in summer in Rushy Creek cannot be confirmed for most of the system because sites were not revisited in February 2013 (see hydrological change theme). Given that several permanent water species were found above the dam (disconnected from the downstream environment), a refuge(s) is likely to exist. The dam constructed on Rushy Creek in 2009 is likely to provide refuge for some species, and permanent pools may exist within the river higher in the catchment. If the dam is the primary refuge then predation by the large number of cormorants present should be considered.

The fish and crayfish sub-index scores for the Rushy Creek system indicate the fish community in the southern tributary (RRAP10) and bottom of catchment (RUSHYCK) are largely unmodified, while those in the main channel (RRAP6) and northern tributary (RRAP9) are slightly modified. The modifications were due largely to the absence of a few native species at individual sites. No obvious spatial pattern in the absence of expected species was observed. Notably, there is little evidence in the fish and crayfish sub-index scores to suggest the dam on Rushy Creek is affecting fish communities in the system. This supports findings by Beatty et al. (2012) who found no clear signal that native species were being impeded by the dam (e.g. species were not seen congregating at the base of the fishway and *G. occidentalis, B. porosa* and *P. olorum* were shown to successfully negotiate the fishway). There is uncertainty about the ability of *T. bostocki* to move through the area, however given that there doesn't appear to be a large population of *T. bostocki* in the system – based on data collected in the upper catchment before dam construction (Beatty et al. 2008) and studies of fish below the dammed area (Beatty et al. 2012 and this study) – this may not be a significant issue.

5.3 Upper Chapman Brook

Based on the SWIRC scores, the Upper Chapman Brook was generally in good condition, with the majority of the ecological theme index scores across the four reaches being categorised as largely unmodified or slightly modified (top two condition bands), and the remainder being moderately modified (Figure 56). The one exception was the aquatic biota index score for the upper catchment site, UCHAP1, which was categorised as severely modified (see aquatic biota theme).

At the sub-index and component level, there was a greater degree of variability in condition, with sites in the mid catchment (UCHAPX2 and UCHAP5) showing substantial modification within some of the sub-indices.

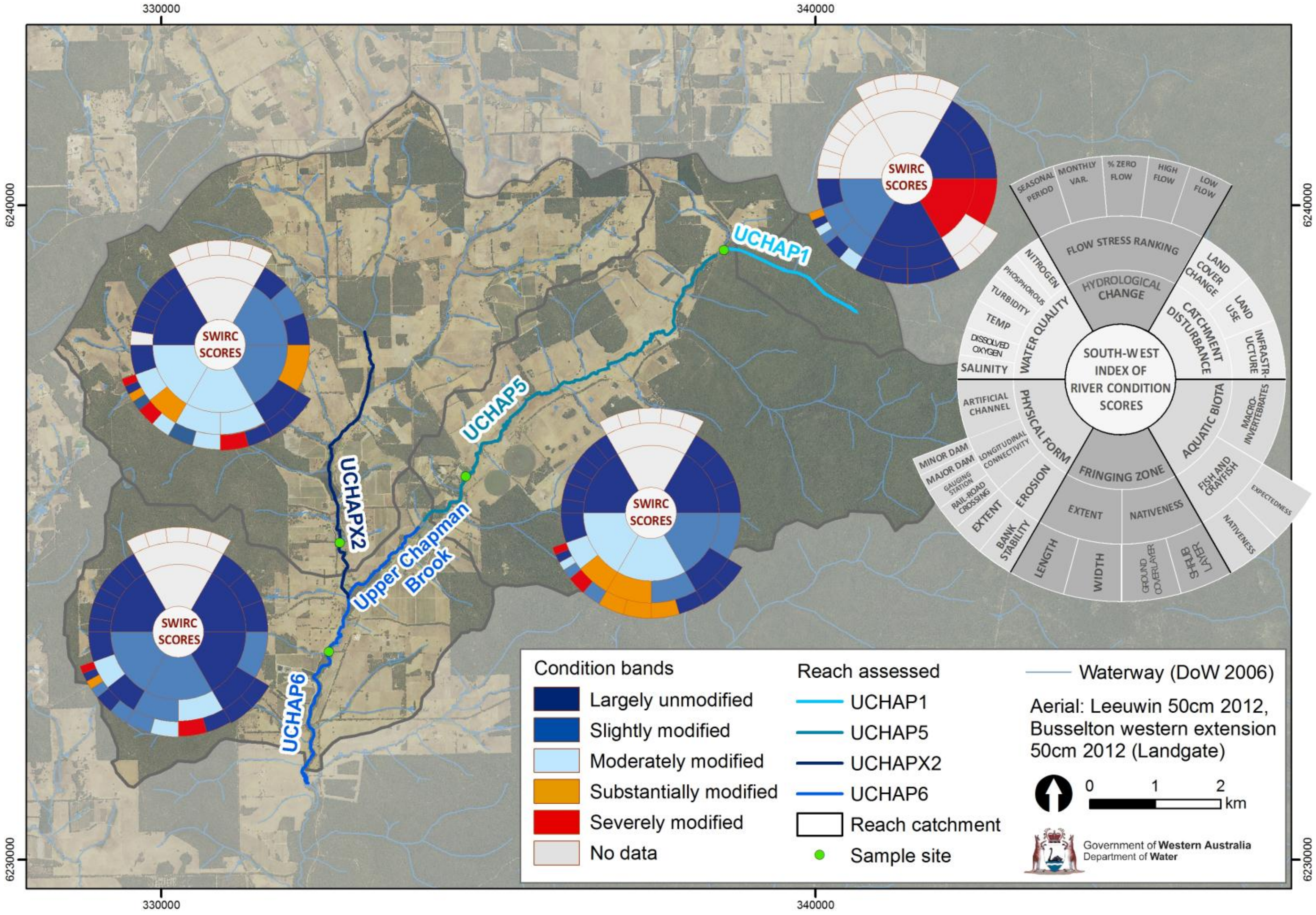


Figure 56 SWIRC scores for Upper Chapman Brook reaches (October 2012 assessment)

5.3.1 Theme: catchment disturbance

Based on 2007 land use data, the portion of the Upper Chapman Brook catchment assessed in this study was characterised by conservation/minimal use (60%) towards the outer edges of the catchment, with grazing (30%) through the central part of the catchment surrounding the brook. The remainder of the catchment was used for intensive/irrigated agriculture (7%), urban/transport/mining (2%) and plantation forestry (1%). Within the four reach catchments of the Upper Chapman, the proportions of land use varied slightly compared with the catchment as a whole. Using the land use sub-index, the impact to river health was categorised as largely unmodified for the upper and mid catchments (reaches UCHAP1, UCHAP5 and UCHAP6), and slightly modified for the northern tributary reach catchment, UCHAPX2.

There was no change in vegetation cover between 2007 and 2011 for reach catchment UCHAP1, and a gain of less than 1% in area for each of the other reach catchments. Given there was no loss of perennial vegetation, all four reach catchments were categorised as largely unmodified using the land cover change sub-index scores.

The proportion of each reach catchment covered by infrastructure was low (between 0.9% and 1.1%), hence the infrastructure sub-index scores were in the top condition band (largely unmodified) for all four reach catchments.

When the three sub-index scores were integrated, the resulting catchment disturbance index scores for all four reach catchments were in the top two condition bands (largely unmodified to slightly modified).

5.3.2 Theme: hydrological change

Sub-theme: flow stress ranking

The flow stress ranking sub-index was not calculated for Upper Chapman Brook due to insufficient flow data.

Sub-theme: farm dams

The Upper Chapman Brook had a farm dam density of 13 ML/km^2 and development of 7%, indicating that approximately 7% of the mean annual flow for the catchment can be held within farm dams.

The density and development was higher than McLeod Creek, and lower than Chapman Brook and Rushy Creek, and falls within the middle of the range calculated for a selection of catchments in south-west Western Australia, which showed a density of between 2 and 27 ML/km^2 and development between 1 and 17% of mean annual flow (SKM 2009).

Supplementary information – observations of permanent water

With the exception of the upper catchment site (UCHAP1), Upper Chapman Brook appeared to be flowing in June and October 2012. In February 2013, flowing water was only observed at two of eight locations: UCHAPX2 (on the northern tributary) and UCHAP5 (in the mid catchment, upstream of the tributary confluence) (Figure 28).

Upper Chapman Brook overlies the sedimentary aquifers of the Perth Basin (Figure 4) and thus it is possible that groundwater sources contributed to the surface water observed in February 2013. The Chapman Brook system is considered to be a potentially connected system; that is, one where interaction occurs between surface and groundwater (Goodreid 2008), however insufficient data are available to determine the connectivity with certainty (Rodgers 2007). The Department of Water is developing environmental flow requirements for the Chapman Brook system, which may provide further information about connectivity. It is also possible that outflow or leakage from the two dams (combined capacity of 379 000 KL) located upstream of site UCHAPX2 contributed to the presence of surface water flow in February 2013.

5.3.3 Theme: fringing zone

Based on the fringing vegetation index scores, the fringing zone of the Upper Chapman Brook was largely unmodified in the upper catchment, but was slightly to moderately modified in the mid catchment and northern tributary reaches.

Upper catchment (upstream of tributary confluence) – UCHAP1

The extent of fringing zone in the upper catchment (UCHAP1) was high, with 100% of the reach length vegetated and an average width of 50 m or greater on each bank. (Note: a maximum width of 50 m was assessed, however the actual width is likely to be much greater given most of the catchment (97%) is reserved for conservation/minimal use.) Of the fringing vegetation present at the site, only a very small proportion was exotic: 1 to 10% of the ground cover layer on the right bank – at the downstream end of the site where the track crossing was located. The fringing zone index score for this reach was categorised as largely unmodified.

Mid catchment (upstream of tributary confluence) – UCHAP5

Reach UCHAP5 was the least vegetated in the Upper Chapman Brook, with only 34% of the length covered by fringing vegetation, and an average width of 13 m on each bank. Site UCHAP5 was well vegetated, with a dense tree layer (75–100% cover of trees >10 m tall, 10–50% cover of trees <10 m tall), 50 to 75% cover provided by the shrub layer and 50 to 100% cover of ground cover vegetation. Exotic species were not observed in the shrub or tree layers, but comprised 50 to 75% of the ground cover present. When combined using the fringing zone index score, the reach was categorised as moderately modified.

Northern tributary – UCHAPX2

The reach of the northern tributary of Upper Chapman Brook (UCHAPX2) had fringing vegetation cover along 62% of the reach length, with an average width of 20 m on each bank.

The fringing vegetation at the site UCHAPX2 was characterised by a fairly dense canopy of trees: 10 to 50% cover of trees <10 m tall, and between 10 to 75% cover of trees >10 m tall. Below this canopy layer, the cover of shrubs and ground cover was less dense (10–50%

cover provided by each layer). A high proportion of bare ground, including leaf litter, was observed (50–75% cover). Exotic species dominated the ground cover layer (75–100% of the vegetation present) and was present (1–10 %) in the shrub layer. The right bank at the site was not fenced off from the adjacent paddock, potentially allowing stock grazing which may have reduced the shrub and ground cover layers and allowed exotic species of ground cover to establish.

Using the fringing zone index score, the reach was categorised as moderately modified.

Mid catchment (downstream of tributary confluence) – UCHAP6

Seventy-four per cent of the length of reach UCHAP6 was covered by fringing vegetation, with an average width of 28 m on each bank. At site UCHAP6 the fringing vegetation was dense, with 75 to 100% cover of ground cover and shrub layers, and 50 to 75% cover of trees <10 m tall. Trees >10 m tall were absent from the left bank, but provided 1 to 10% cover on the right bank. No exotic species were observed in the shrub and tree layers, however they formed 50 to 75% of the ground cover layer on the right bank, and 75 to 100% on the left bank. The exotic ground cover species were dominated by grasses, with the adjacent paddock extending to the waterline in places. The fringing zone index score for this reach was categorised as moderately modified.

5.3.4 Theme: physical form

The physical form index scores for Upper Chapman Brook indicated the reaches to be slightly to moderately modified.

Based on desk-top data two potential minor dams were identified on each reach (with the exception of reach UCHAP1), along with a number of road crossing points on each reach, which may prevent the movement of biota through the creek. Ground-truthing of these potential barriers is recommended to confirm the presence of any structures, and the extent to which they may prevent biota movement. Given the potential presence of barriers, the longitudinal connectivity sub-index scores indicated all four reaches were slightly unmodified or moderately modified.

At the upper and mid catchment sites (UCHAP1 and UCHAP6) the extent of erosion was low (0–5% of the site length), while the fringing vegetation was dense (see fringing zone theme), providing a bank stabilisation function. The erosion sub-index scores for these sites were slightly modified and largely unmodified respectively.

At sites in the mid catchment and northern tributary (UCHAP5 and UCHAPX2) the extent of erosion was high (50–100% of the site length), despite the bank stabilisation provided by vegetation (UCHAP5 was well vegetated, while UCHAPX2 had a dense tree canopy and sparse shrub layer; see fringing zone theme). This suggests the erosion may be caused by other factors such as scouring during high flow events – further work is needed to confirm this. The erosion sub-index scores were categorised as substantially modified for both sites.

5.3.5 Theme: water quality

The water quality index scores for October 2012 suggest that the Upper Chapman Brook sites were largely unmodified.

Water quality parameters were within guidelines at all sites, with several exceptions:

- At UCHAP5, a total nitrogen concentration of 4.1 mg/L was recorded in June 2012 (exceeding the guideline of 1.2 mg/L (ANZECC & ARMCANZ 2000a). Concentrations in October 2012 and February 2013 were just below the guideline at 1.1 mg/L on both occasions. Total nitrogen concentrations measured at UCHAPX2 and UCHAP6 slightly exceeded the guideline in June 2012 (1.3 mg/L and 1.4 mg/L respectively), although were below guideline on other sampling occasions. Total oxidised nitrogen (nitrate and nitrite) was the dominant species, accounting for 75% of the total nitrogen at all three sites in June 2012. As discussed for McLeod Creek, this suggests the total nitrogen may be from fertiliser applied to the reach catchment, although further sampling would be required to confirm this.
- At site UCHAP5 in June 2012, turbidity was 30 NTU and total suspended solids was 32 mg/L, compared with the respective guideline values of 10 to 20 NTU (ANZECC & ARMCANZ 2000a) and 6 mg/L (DoW unpublished data). The cause of the high turbidity is unknown; further sampling is required to determine whether it was the result of a single disturbance event in the catchment or is representative of turbidity at this site.

  Note: the high turbidity at UCHAP5 in June 2012 coincided with the elevated total nitrogen concentration discussed previously, however, given the high proportion of total oxidised nitrogen present (soluble rather than particulate in form), it is unlikely that particulates were the mode of transport for the total nitrogen. This also coincides with the highest total phosphorus concentration recorded in the study of 0.045 mg/L (0.02 mg/L below the ANZECC & ARMCANZ (2000a) guideline). Given that phosphorus is known to bind to particulates, this suggests the suspended solids may have been the mode of transport for the phosphorus.
- At site UCHAPX2, the diel dissolved oxygen in February 2013 was around or below 5 mg/L for the entire 24-hour period recorded. The rate of flow was below the detection limit of the flow meter (trickle flow over riffles was the only visual evidence of movement). It is likely that the lack of turbulence and mixing of water, and the associated lack of oxygenation, contributed to the low dissolved oxygen concentration at the site. Further sampling is required to determine the spatial and temporal extent of low dissolved oxygen in the creek.

Non-nutrient contaminants were assessed at three sites: UCHAP1, UCHAP5 and UCHAP6. Concentrations above the laboratory limits of reporting were not recorded for any of the pesticides or herbicides assessed in this study. Some caution should be applied when interpreting these results as many of the available guidelines are set at concentrations lower than current analytical methods are able to achieve.

A number of metals were detected in sediment at these sites, however they were all at concentrations below available guidelines. Although no guideline exists for aluminium and iron, these metals are ubiquitous in south-west aquatic systems and were within ranges previously recorded in south-west Western Australian systems (e.g. Nice et al. 2009; Storer et al. 2013). No correlation was obvious between metal concentrations and particle size.

5.3.6 Theme: aquatic biota

The aquatic biota index scores for Upper Chapman Brook indicated the sites range from largely unmodified (UCHAP6) to slightly modified (UCHAP5 and UCHPX2), with the exception of UCHAP1 which was categorised as severely modified based on the macroinvertebrate community present in shallow stationary water (this score should be interpreted with caution, see discussion for UCHAP1).

Sub-theme: macroinvertebrates

Thirty-seven taxa were found within the Upper Chapman Brook catchment. Taxa richness at each site ranged from nine to sixteen distinct taxa. Total abundance per site ranged from 47 to 184 individuals.

Notable taxa collected in Upper Chapman Brook include:

- New larval form(s) of *Notoperata* (caddisfly larvae) were found at one site (UCHAP6). As discussed for McLeod Creek, it is unclear at this stage whether these are a new species or simply a larval form from an existing species that had not been collected previously (Rosalind St Clair pers. comm. 2013).
- The freshwater mussel, *W. carteri*, was observed at three of the four sites. As discussed for McLeod Creek, this species is listed as Priority 4 (rare, near threatened and other species in need of monitoring) by DPaW (2013).

Using the macroinvertebrate sub-index, the condition of the sites ranged from slightly modified to severely modified.

Upper catchment – UCHAP1

Site UCHAP1 had a taxa richness of nine, and a total abundance of 41 animals. The community composition at the site was dominated by Insecta (63% of total abundance), with the remaining animals in the Crustacea class (37%). Arachnida, Gastropoda and Oligochaeta classes were absent. Only one EPT taxa was found and in low abundance (10% of total abundance).

The Priority 4 species, *W. carteri* (DPaW 2013), was observed at this site.

Using the macroinvertebrate sub-index scoring protocol, the site was categorised as severely modified, suggesting the community composition was different to that expected under reference conditions. This is not surprising, given that the reference sites within the WA AUSRIVAS spring channel model (used to generate the sub-index score) were sampled under flowing conditions (Halse et al. 2001). It is not known whether the shallow disconnected conditions observed at this site in February 2013 are typical for this system, or reflect drying climate conditions – as such this score should be interpreted with caution.

Further sampling at a greater temporal scale is suggested to determine seasonal and annual variations in the macroinvertebrate community composition.

Mid catchment (upstream of tributary confluence) – UCHAP5

At UCHAP5, 15 distinct taxa and a total abundance of 47 animals were found. The abundance was dominated by the predacious diving beetle, *Sternopriscus marginatus*. This species is salt tolerant (MDFRC 2013), thus suggesting the site may experience intermittent increases in salt concentration – although the water quality results showed this site was fresh on all three water quality sampling occasions (see water quality theme).

Two EPT taxa were present in low numbers (six individuals in total).

The Priority 4 species, *W. carteri* (DPaW 2013), was observed at this site.

The study's highest proportional abundance of predators (57%) was found at this site. Overseas studies have correlated a high ratio of predators with prey species with a short lifecycle and corresponding high turnover rates; a high productivity of prey species would require large amounts of benthic organic matter (Yamauro & Lamberti 2007 cited in WRM 2011). This was supported by in-stream observations where silt accounted for 90% of the available mineral substrate, which appeared to be dominated by organic matter.

The macroinvertebrate sub-index score for site UCHAP5 was categorised as slightly modified, indicating that the community composition found was similar to that expected under reference conditions.

Western tributary – UCHAPX2

UCHAPX2 had a taxa richness of 16 and total abundance of 54 animals. Shredders were absent from the trophic structure, although all other functional feeding groups were represented. The absence of shredders is unexpected given the in-stream habitat surface area included a dense cover of detritus (70% cover). Further sampling at a greater temporal scale is required to determine whether the absence of shredders was an anomaly, or indicates a disturbance not detected during sampling.

The Priority 4 species, *W. carteri* (DPaW 2013), was observed at this site.

The macroinvertebrate sub-index score of substantially modified obtained at site UCHAPX2 indicates the community composition was different to that expected under reference conditions.

Mid catchment (downstream of tributary confluence) – UCHAP6

Sixteen macroinvertebrate taxa and a total abundance of 184 animals were found at UCHAP6 in the mid catchment. Chironomidae dominated the abundance (84%). As discussed for other systems, this may suggest the occurrence of nutrient enrichment or increasing heavy metal concentration (Burton & Pitt 2002) or warm waters and low flows (Bunn et al. 1986). At the time of macroinvertebrate sampling in October 2012, nutrient and metal concentrations at UCHAP6 were below the available guidelines (ANZECC & ARMCANZ 2000a), however total nitrogen was slightly elevated in June 2012. The water was cool, with a diel temperature range of 16 to 18 °C (below the mean maximum temperature for all study sites of 19 °C ± 3 °C), and fast flowing (0.16 m/s) (see water quality theme). Four EPT taxa were collected here, further suggesting this site has acceptable water quality and in-stream habitat (e.g. Barbour et al. 1999).

This site was dominated by collectors (Chironomidae) with very few shredders, grazers and predators present (see Figure 43). A greater proportion of predators and shredders would be expected at an undisturbed site (WRM 2011). Collectors tend to dominate in disturbed reaches where the input of fine particulate matter is high (WRM 2011), however, this did not appear to be the case at this site, because the concentration of total suspended solids and silt was low (<1 mg/L and 10% cover respectively) in October 2012.

New larval form(s) of *Notoperata* (caddisfly larvae) were found at this site.

Based on the macroinvertebrate sub-index score for October 2012, site UCHAP5 was slightly modified, indicating the community composition found was similar to that expected under reference conditions.

Sub-theme: fish and crayfish

The Upper Chapman Brook supported a high richness of fish and crayfish, with eight species in total including four native freshwater fish (*G. occidentalis, G. munda, N. vittata* and *B. porosa*), three freshwater crayfish (*C. cainii, C. crassimanus* and *C. quinquecarinatus*), and the only record of *Geotria australis*. (Note: a list of common names of fish and crayfish is provided at the end of the Glossary.)

Richness was relatively consistent across the catchment with seven species found at UCHAP5 and six species at UCHAPX2 and UCHAP6. This richness is high for south-west Western Australian river systems, where it is rare to find more than six native species at any one site (Storer et al. 2011b). *G. occidentalis, N. vittata, B. porosa, C. cainii* and *C. quinquecarinatus* were found at all sites, while *G. munda* was only at UCHAP6, *G. australis* at UCHAP5 and *C. crassimanus* only at UCHAPX2.

With the exception of juvenile *C. cainii*, no evidence was found to support the system as a nursery for fish species during October 2012. However, in the subsequent sampling event in February 2013, juveniles were found at sites in the mid catchment (UCHAP5) and the northern tributary (UCHAPX2). Juvenile *N. vittata* and *C. quinquecarinatus* were found at both sites, while juvenile *G. occidentalis* were captured at UCHAPX2 and *C. cainii* and *G. australis* at UCHAP5. This supports the system being both an important nursery for several fish and crayfish species and a potential refuge during the summer months – which may include species migrating from Chapman Brook. Total abundance at the UCHAPX2 site more than doubled in the February sample, due primarily to increases in *G. occidentalis* and *N. vittata*, and there was an increase in C*. crassimanus* and *G. munda* abundance at the UCHAP5 site, which supports these sites as refugia.

Based on visual observations of distended abdomens in October 2012, gravid *B. porosa* were observed in the mid catchment site UCHAP6, and gravid *B. porosa* and *G. occidentalis* were found at the northern tributary site UCHAPX2. In February 2013, gravid *G. occidentalis* and *N. vittata* were recorded at UCHAPX2. This suggests the area is a likely spawning ground for these species.

Based on data from October 2012, the fish and crayfish sub-index scores were in the top condition band for the three sites sampled in the Upper Chapman Brook (not including UCHAP1 which was dry). This reflects the low number of exotics and presence of most of the species expected for the system. Only one expected species, *G. australis*, was not found at any site in October 2012; this finding is not surprising given the catchability of this species is variable and site dependent.

5.4 Chapman Brook

Based on the SWIRC scores, Chapman Brook was generally in good condition, with the majority of the five ecological theme index scores at both reaches being categorised as largely unmodified or slightly modified (top two condition bands), and the remainder being moderately modified (Figure 57).

The sub-index and component scores, and the underlying data, showed that the ecological condition of the upper and lower catchments were very similar; the only notable differences were in the community composition of the aquatic biota.

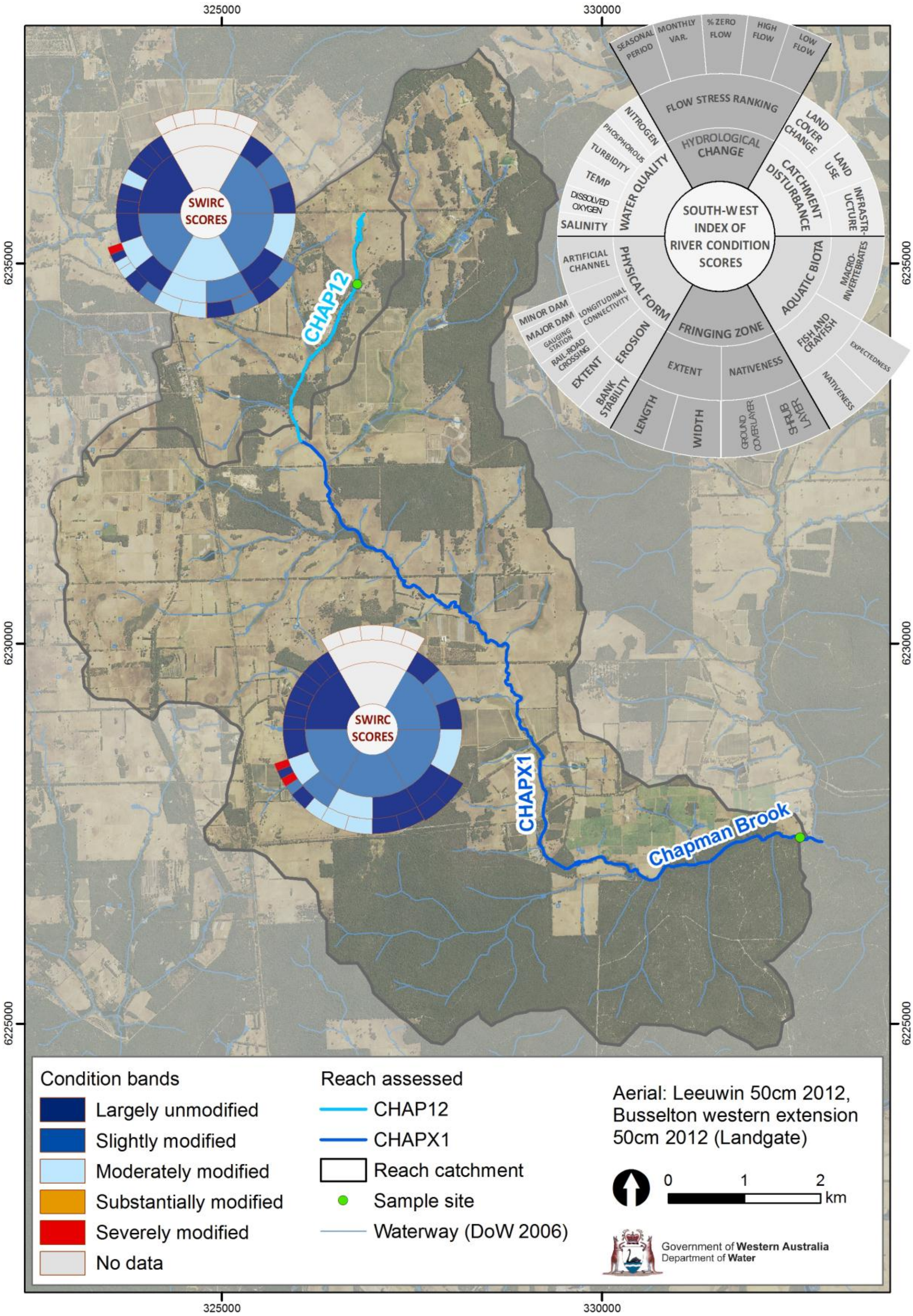


Figure 57 SWIRC scores for Chapman Brook reaches (October 2012 assessment)

5.4.1 Theme: catchment disturbance

Based on 2007 land use data, the catchment of the upper reach, CHAP12, was characterised by grazing land (56%) and conservation/minimal use (32%), with the remaining area covered by intensive uses such as irrigated agriculture and residential development. The lower reach catchment, CHAPX1, had a higher proportion of conservation/minimal use (48%), which was primarily concentrated within Blackwood River National Park at the catchment's downstream end. Grazing accounted for 41% of the area of the lower reach catchment, with the remainder covered by intensive uses. Using the land use sub-index, the impact of land use on river health in both reach catchments was categorised as slightly modified.

In both reach catchments there was a loss of vegetation cover equivalent to 1% of the area of each reach catchment between 2007 and 2011, providing a land cover change sub-index score of largely unmodified.

The proportion of each reach catchment covered by infrastructure was low (between 1.1 and 1.3%), consequently the infrastructure sub-index scores were in the top condition band (largely unmodified).

When the three sub-index scores were integrated, the resulting catchment disturbance index scores for both reach catchments were categorised as slightly modified.

5.4.2 Theme: hydrological change

Sub-theme: flow stress ranking

The flow stress ranking sub-index score for Chapman Brook was 0.7 and the associated hydrological change index score was categorised as slightly modified.

The high flow component of the flow stress ranking received a low score (0.3 out of 1.0), indicating that the magnitudes of the high flows are significantly departed from reference condition. This can partly be attributed to the clearing of vegetation in the catchment (approximately 60% cleared[12]) (vegetation clearing causes changes in the hydrological cycle that can result in increased runoff). High flow events are an important aspect of the flow regime. They regulate ecosystem processes, re-organise substrate habitat and transport sediment and organic material. They also cause a rise in water level and inundation, which are cues for animals to spawn or emerge from rest (Bunn & Arthington 2002). High velocity flows can cause erosion problems such as bank scour, slumping and undercutting.

Interestingly, the low flow component scored 1.0 out of 1.0, indicating little or no departure from reference condition. This was a common occurrence in previous work throughout south-west Western Australia due to the seasonal nature of some south-west rivers (Storer et al. 2011a).

[12] Department of Agriculture and Food's Native vegetation current extent dataset, see Appendix Z.

The proportion of zero flow scored 0.8 out of 1.0. This is due to Chapman Brook having a smaller proportion of zero flow months, at 22% in comparison with 33% of zero flow months in the Weld River tributary.

Sub-theme: farm dams

Chapman Brook had a farm dam density of 24 ML/km^2 and development of 10.4%, indicating that approximately 10% of the mean annual flow for the catchment can be held within farm dams.

The density and development were higher than McLeod Creek and Upper Chapman Brook but lower than that for Rushy Creek. It falls within the upper end of the range calculated for a selection of catchments in south-west Western Australia, which showed a density of between 2 and 27 ML/km^2 and development between 1 and 17% of mean annual flow (SKM 2009).

Supplementary information – observations of permanent water

Both sites were flowing in June and October 2012, and dry in February 2013. Two additional locations in the upper catchment (crossings at Rowe Road and Davis Road, Figure 28) were also observed to be dry in February 2013 (a disconnected pool was present at Davis Road downstream of the culvert, which may have been artificially deepened).

5.4.3 Theme: fringing vegetation

Based on the fringing vegetation index scores, the fringing zone of Chapman Brook was moderately modified in the upper catchment (CHAP12) and slightly modified in the mid to lower catchment (CHAPX1).

Fringing vegetation was present along approximately 50% of both reach lengths, while the average width of fringing vegetation was 22 m on each bank. This was slightly lower than the average lengths and widths for the study area (mean vegetated length 65% ± 25; mean width 28 m ± 13 m). The resulting fringing zone extent sub-index scores indicated both reaches were moderately modified.

At site CHAP12, in the upper catchment, there was a high proportion of exotic species in the shrub layer (10–50%) compared with all other study sites, due to the presence of blackberry and thistles. The nativeness sub-index score indicated the site was slightly modified. Note: weed control has been undertaken at this site in recent years.

At site CHAPX1, in the lower catchment, no exotic plant species were observed, hence the nativeness sub-index score was in the largely unmodified category.

5.4.4 Theme: physical form

The physical form index scores for Chapman Brook indicated the reaches to be slightly modified.

The extent of erosion at both sites was limited (0–5% of the site length). The shrub layer provided dense cover (75–100%) within the streamside zone at both sites, with moderate to dense tree cover (combining cover for trees <10 m and >10 m tall). This vegetation cover may provide the banks with protection from erosion. Using the erosion sub-index, the site scores were categorised in the top two condition bands: largely unmodified (CHAP12) and slightly modified (CHAPX1).

Nine potential minor dams were identified on reach CHAP12, and four potential minor dams and two gauging stations on to reach CHAPX1. Ground-truthing of these potential barriers is recommended to confirm the presence of any structures, and the extent to which they may prevent biota movement. Given the potential presence of barriers, the longitudinal connectivity sub-index scores indicated both reaches were moderately modified.

5.4.5 Theme: water and sediment quality

The water quality index scores for October 2012 suggest the Chapman Brook sites were largely unmodified.

Water quality parameters were within guidelines at both sites with one exception: at site CHAP12 the total nitrogen concentration in June 2012 was slightly above the ANZECC & ARMCANZ (2000a) default trigger value (1.9 mg/L compared with 1.2 mg/L). Total oxidised nitrogen (nitrate and nitrite) was the dominant species, accounting for 53% of the total nitrogen. As discussed for McLeod Creek, this suggests the total nitrogen is derived from fertiliser applied to the reach catchment, although further sampling would be required to determine the source. The water quality index and associated sub-indices, calculated for October 2012, indicated both sites to be in the highest condition band (largely unmodified).

For the pesticides and herbicides assessed at site CHAP12, concentrations above the laboratory limits of reporting were not recorded (some caution should be taken when interpreting these results, see Upper Chapman Brook discussion).

A number of metals were detected in sediment at CHAP12 but they were all at concentrations below available guidelines. No correlation was obvious between metal concentrations and particle size. The level of iron recorded at CHAP12 was higher than the sites on the Upper Chapman; this is likely a function of iron flocculent, given that particle size analysis showed the sediment was comprised predominantly of coarse sand and gravel. This was supported by visual observations of iron flocculent at the site in October 2012.

5.4.6 Theme: aquatic biota

The aquatic biota index scores for Chapman Brook indicated the sites were slightly modified.

Sub-theme: macroinvertebrates

Twenty-eight taxa were found within the Chapman Brook catchment. Taxa richness at the two sites sampled was 10 and 21 respectively. Total abundance per site was 56 and 505 individuals.

For both Chapman Brook sites, the community composition was different to that expected under reference conditions, resulting in a macroinvertebrate sub-index score of moderately modified.

Upper catchment – CHAP12

At CHAP12, 21 taxa and a total abundance of 505 animals were collected. Chironomidae constituted 70% of the sample population, 78% of which were *Chironomus* spp. These species are typical of organically polluted waters (Gooderham & Tsyrlin 2002). Warm waters and low flows also favour Chironomidae (Bunn et al. 1986). At the time of macroinvertebrate sampling (October 2012), nutrient and metal concentrations at CHAP12 were below the available guidelines (ANZECC & ARMCANZ 2000a), however total nitrogen was slightly elevated in June 2012. Water was shallow (<25 cm) and slow flowing (flow rate below detection using the Global flow meter), which may have favoured Chironomidae (Bunn et al. 1986). In addition, iron flocculent was observed, which can smother the gills of macroinvertebrates such as some EPT taxa (MDFRC 2013).

This site also had the highest abundance of Oligochaeta of any site. This group is capable of living in enriched systems with low oxygen and silty sediments (Gooderham & Tsyrlin 2002). Further sampling at a greater temporal scale is required to determine seasonal fluctuations in water quality and macroinvertebrate community composition.

The trophic structure of the community was dominated by collectors (82% of total abundance) and shredders were absent. Collectors are generalists that can use a broad range of food sources; they are therefore considered more tolerant to pollution that might alter food availability (Barbour et al. 1999). They also tend to dominate in disturbed reaches where the input of fine particulate matter is high (WRM 2011). This did not appear to be the case here because the total suspended solids concentration was low (<1 mg/L in October 2012). The presence of iron flocculent, which alters habitat availability at the site, may have contributed to the dominance by collectors.

Lower catchment – CHAPX1

CHAPX1 had a taxa richness of 10 and a total abundance of 56 animals. While the taxa richness and total abundance were low compared with other sites in the study, CHAPX1 had the highest proportional abundance of EPT taxa of all the sites (46% of total abundance). EPT taxa are generally sensitive (less tolerant) to stress and often have specific habitat requirements, hence their presence is often an indicator of undisturbed or 'healthy' streams (e.g. Barbour et al. 1999). Given this, the high proportional abundance of EPT taxa at CHAPX1 could be attributed to water quality parameters that were within guidelines (see water quality theme) and the diverse in-stream habitat observed at the site (e.g. a variety of substrate types, a complexity of detritus and woody debris reflecting an intact riparian zone, shaded and open canopy areas, and riparian vegetation draped in water).

The low taxa richness and total abundance compared with other sites in the study may be a natural phenomenon; Bunn & Davies (1990) suggested that south-west Australian streams have a depauperate macroinvertebrate fauna relative to south-eastern Australia. However the absence of stonefly at the site may suggest either some disturbance not detected during sampling or habitat conditions not being sufficient for this group, which tend to be more sensitive than mayflies (Ephemeroptera) and caddisflies (Trichoptera) (Harrington & Born 2000).

The community composition at the site was dominated by Insecta (75% of total abundance), with the remaining animals in the Crustacea class (25%). Dominance by insects is typical in seasonally flowing south-west rivers where they typically account for 70 to 80% of the total abundance (WRM 2007b; WRM 2011).

Sub-theme: fish and crayfish

Chapman Brook supported six native species of fish and crayfish, including three freshwater fish (*G. occidentalis, N. vittata* and *B. porosa*) and three freshwater crayfish (*C. cainii, C. crassimanus* and *C. quinquecarinatus*). (Note: a list of common names of fish and crayfish is provided at the end of the Glossary).

All six species were present at the lower site (CHAPX1) in October 2012. This species richness is high for south-west Western Australian river systems, where it is rare to find more than six native species at any one site (Storer et al. 2011b). At the top of the catchment (CHAP12) only two species were collected (*G. occidentalis* and *C. quiquecarinatus*) in October 2012. (Note: both sites were dry in February 2013).

The species distribution through Chapman Brook may reflect the permanency of water. The presence of *G. occidentalis* and *C. quinquecarinatus* at the top of the catchment may reflect their individual strategies for drought, with *G. occidentalis* being highly mobile (able to retreat to more permanent water as levels subside) and *C. quinquecarinatus* being able to burrow into sediment to maintain contact with the receding water table. The higher richness in the lower catchment may in turn reflect the closer proximity to permanent water in either the lower Chapman Brook or Upper Chapman Brook. The possibility of the Upper Chapman Brook providing permanent water refuge for Chapman Brook fish populations is supported by a parallel increase in abundance of fish within the Upper Chapman Brook study sites at the time of drying in the Chapman Brook. A comprehensive survey of the brooks would be required to determine the location of any permanent water through summer.

No juveniles of any species were recorded in the Chapman Brook sites, suggesting the nursery areas for the species present are located in other tributaries.

The fish and crayfish sub-index scores for both sites suggest the community is largely unmodified. At site CHAP12, in the upper catchment, the expected species list included *C. cainii* (based on a literature source suggesting broad distribution of this species before European settlement), but given the site is at the top of the catchment, and was dry in February 2013, the natural range of *C. cainii* may not have extended that far. At CHAPX1, only one expected species was not found: pouched lamprey. This expectation was interpolated based on the findings of previous studies of Upper Chapman Brook and Blackwood River.

5.5 Fisher Creek

Based on the SWIRC scores, Fisher Creek was in good condition, with the five ecological theme index scores being in the top condition band (largely unmodified). The sub-index and component scores were all in the top two condition bands (largely unmodified and slightly modified) (Figure 58).

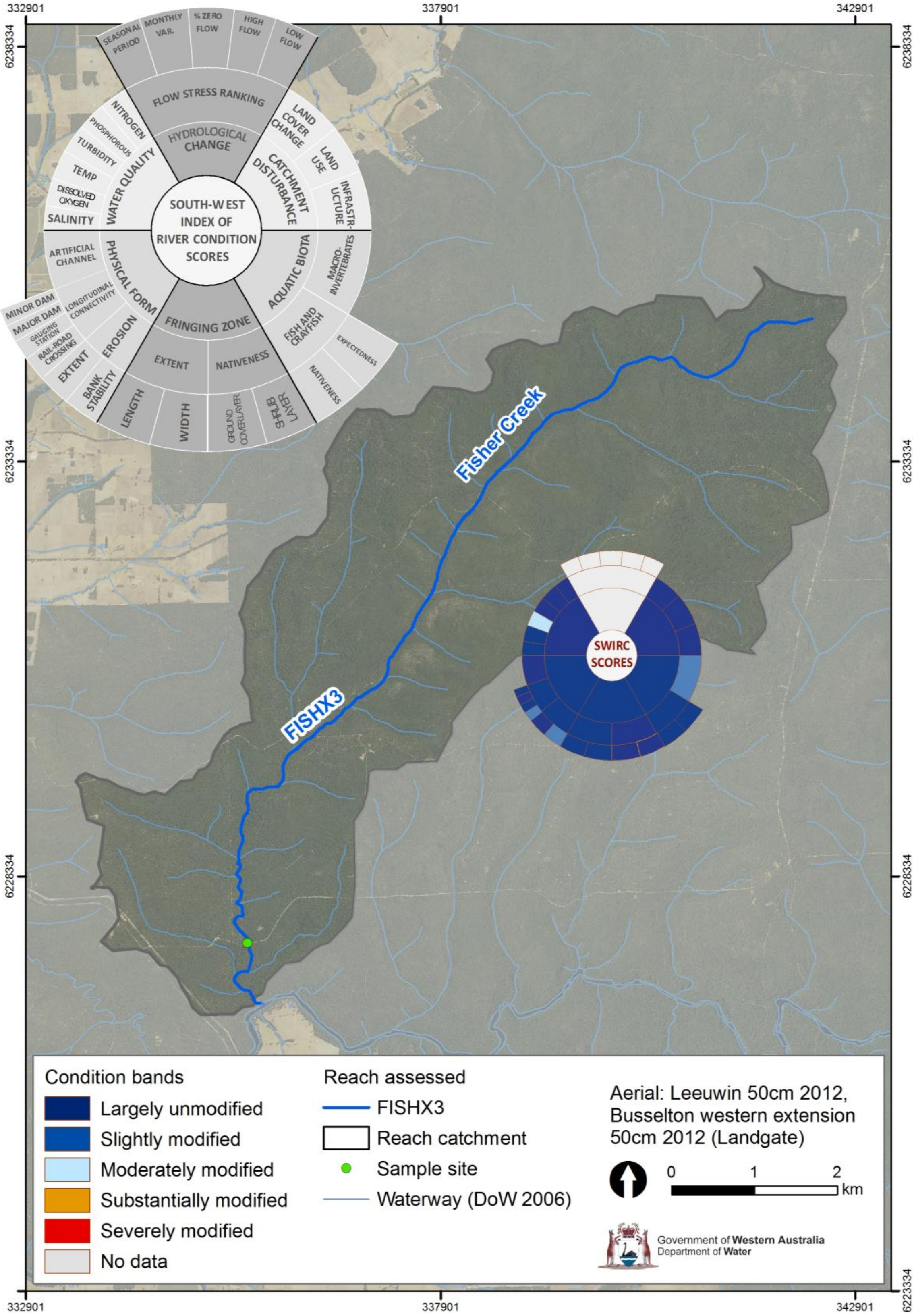


Figure 58 SWIRC scores for Fisher Creek reach (October 2012 assessment)

5.5.1 Theme: catchment disturbance

The FISHX3 catchment was dominated by conservation/minimal use (99%) with transport (tracks) being the only other use (covering 1% of the catchment area).

No loss or gain of perennial vegetation was detected between 2007 and 2011.

The proportion of the reach catchment covered by infrastructure was low (0.7%), thus the infrastructure sub-index score indicated the catchment was largely unmodified.

Combining the three sub-index scores, the catchment disturbance index score for the catchment was categorised as largely unmodified.

5.5.2 Theme: hydrological change

Sub-theme: flow stress ranking

The flow stress ranking sub-index was not calculated for Fisher Creek due to insufficient flow data.

Sub-theme: farm dams

No farm dams were mapped within the catchment of Fisher Creek.

Supplementary information – observations of permanent water

Site FISHX3 was observed to be flowing in June and October 2012, but dry in February 2013. No other observations of the reach were made; a comprehensive survey of the creek is recommended to determine the location of any permanent water refugia.

5.5.3 Theme: fringing zone

The fringing zone index score for Fisher Creek indicated the reach was largely unmodified.

The full length of reach FISHX3 was covered by fringing vegetation, with an average width of 49 m on each bank. Note: a maximum width of 50 m was assessed for this study, however the actual width is likely to be much greater given that the majority of the catchment is reserved for conservation/minimal use. No exotic species were observed at site FISHX3.

5.5.4 Theme: physical form

The physical form index score indicated the Fisher Creek reach, FISHX3, was largely unmodified.

No potential dams or gauging stations were identified on the reach. Five track crossing points were identified which may act as a barrier to biota movement.

The extent of erosion observed at the site was low (0–5%) and the dense vegetation present – 75 to 100% cover of shrubs, 10 to 50% cover of short trees (<10 m height) and 50 to 75% cover of tall trees (>10 m height) – provided stabilisation of the banks.

5.5.5 Theme: water quality

Based on data from October 2012, the water quality index score for site FISHX3 was categorised as largely unmodified.

Water quality parameters were within guidelines on both sampling occasions. Estimated salinity was slightly elevated in June 2012 (642 mg/L, marginal) compared with October 2012 (370 mg/L, fresh). Based on two samples it is not possible to determine whether this elevated concentration is a single event or is typical of the seasonal variation within the creek; further sampling is recommended to determine salinity levels.

5.5.6 Theme: aquatic biota

The aquatic biota community at site FISHX3 appeared to be largely unmodified based on the aquatic biota index score calculated using data from October 2012.

Sub-theme: macroinvertebrates

FISHX3 had a taxa richness of 11, and a total macroinvertebrate abundance of 28, which was the second lowest abundance of the study. This was the only site where Chironomidae was absent. The total abundance was dominated by the Amphipod family Perthiidae. This family is endemic to south-west Western Australia though it is widespread throughout the region (Davis & Christidis 1997).

Three EPT taxa were present including the caddisfly larvae *T. neveipennis AV12*, which Sutcliffe (2003) described as endangered.

The site was dominated by shredders, which tend to be more sensitive to pollution than the more generalist collectors (WRM 2009). Grazers were absent though the reason for this is unclear.

Using the macroinvertebrate sub-index, the site's condition was categorised as slightly modified.

Sub-theme: fish and crayfish

Three freshwater crayfish (*C. crassimanus, C. preissi* and *C. quinquecarinatus*) and one freshwater fish (*G. munda*) were present within Fisher Creek in October 2012. (Note: a list of common names of fish and crayfish is provided at the end of the Glossary.)

The fish community of Fisher Creek has not previously been assessed; however, the observed richness exceeded general expectations based on system characteristics observed through this study. Surface water was present in June 2012 and October 2012, but absent in February 2013, and the system is likely to contain numerous barriers to fish movement given its shallow nature and the considerable amounts of woody debris found at the site. Accordingly only species capable of withstanding drying would be expected.

FISHX3 was the only site where *C. preissii* and juvenile *G. munda* were recorded - this included the presence of post-larvae sized individuals, suggesting a recent spawning event. The data suggests the site is a nursery area for both *G. munda* and *C. crassimanus*.

Exotic species were not recorded in the system, likely due to the drying observed at the site in February 2013.

Due to the absence of exotics and the presence of all species expected, the Fisher Creek site was classed as largely unmodified by the fish and crayfish sub-index.

5.6 Lower Blackwood River

Based on the SWIRC scores, the reach catchment of the lower Blackwood River between the confluence of Chapman Brook and McLeod Creek was generally in good condition, with the four ecological theme index scores assessed (catchment disturbance, fringing zone, physical form and water quality) being in the top two condition bands (largely unmodified and slightly modified). The sub-index scores were also in the top two condition bands (Figure 59).

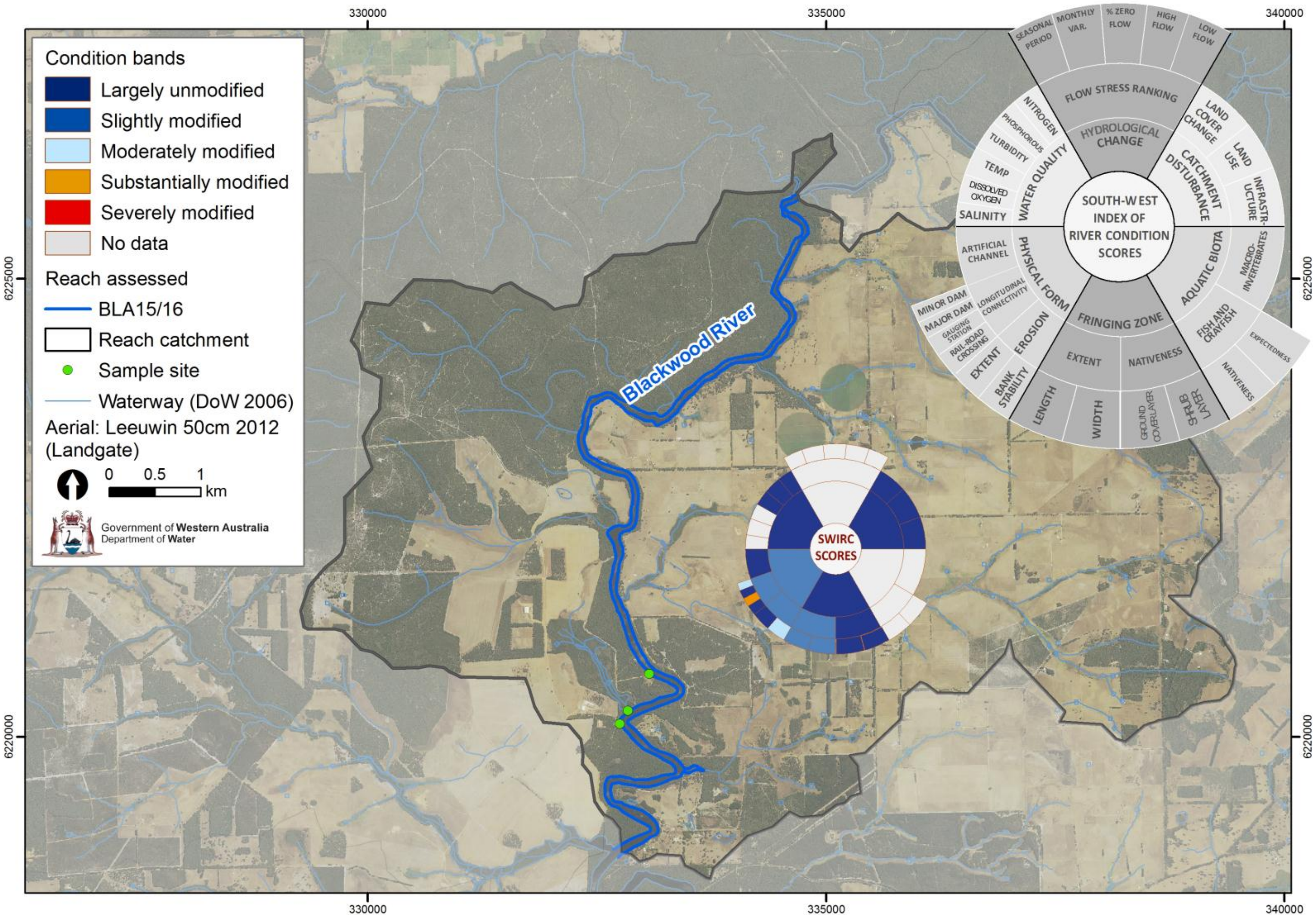


Figure 59 SWIRC scores for the lower Blackwood River reach (October 2012 assessment)

5.6.1 Theme: catchment disturbance

The BLA15/16 catchment was characterised by conservation/minimal use (43%) and grazing (55%) with less than 1% of the catchment area used for plantation forestry, intensive/irrigated agriculture and urban/transport/mining uses.

A loss of perennial vegetation, equating to 1% of the reach catchment area, was detected between 2007 and 2011.

The proportion of the reach catchment covered by infrastructure was low (0.8%), consequently the infrastructure sub-index score was in the top condition band (largely unmodified).

The catchment disturbance index scores for the BLA15/16 reach indicated the catchment was largely unmodified.

5.6.2 Theme: hydrological change

The hydrological change theme was not assessed for the lower Blackwood River reach.

5.6.3 Theme: fringing zone

The fringing zone index score for the lower Blackwood River reach assessed indicated the vegetation to be largely unmodified.

The length of the reach covered by fringing vegetation was 73%, with an average width of 32 m on each bank. No exotic species were observed at site BLA15.

5.6.4 Theme: physical form

The physical form index score indicated the lower Blackwood River reach to be slightly modified.

No potential dams, gauging stations or road crossing points were identified on the reach. A potential minor dam 13 km upstream of the reach and gauging station 2 km downstream of the reach may have affected the movement of biota into the reach.

The extent of erosion observed at the site was low (0–5%) and the dense vegetation present – 50 to 75% cover of shrubs, 1 to 10% cover of short trees (<10 m height) and 50 to 75% cover of tall trees (>10 m height) – provided stabilisation of the banks.

5.6.5 Theme: water quality

Based on sub-indices for total nitrogen, total phosphorus and turbidity measured in October 2012, the water quality index score for reach BLA15/16 was categorised as largely unmodified. (The remaining sub-indices were not assessed in this study, see Section 3.3.)

Water quality parameters were within guidelines at all three sites with several exceptions:

- The total nitrogen concentration measured at site BLA16X (a tributary flowing into the lower Blackwood River) in February 2013 was 3.3 mg/L (compared with the ANZECC & ARMCANZ (2000a) guideline of 1.2 mg/L). Of the total nitrogen, 94% was total oxidised nitrogen (nitrate and nitrite). As discussed for McLeod Creek, this dominance suggests the total nitrogen could be derived from fertiliser application in the catchment, although further sampling would be required to determine seasonal variations and potential sources.

- Total nitrogen concentrations at sites BLA15 (1 km upstream from the tributary confluence) and BLA16 (0.2 km downstream) in February 2013 were 0.37 mg/L and 0.35 mg/L respectively. This suggests the elevated total nitrogen in the tributary became diluted by the volume of water in the Blackwood River, and was not detected as an increased concentration at the site downstream of the confluence.
- Salinity concentrations at sites BLA15 and BLA16 increased from around 1700 mg/L TDS (brackish) in June 2012 to 2700 mg/L (moderately saline) in October 2012 and 3800 mg/L TDS (moderately saline) in February 2013. Given the tidal influence in the Blackwood River extends approximately 42 km inland (Hodgkin 1978) – upstream of these sites – it is possible that the increase in salinity is due to the estuarine water pushing upstream as flows from the Blackwood catchment decrease over spring and summer. The upper catchment of the Blackwood River basin is known to be affected by secondary salinisation, however salinity in the river decreases with distance downstream because of the input of fresh water from tributaries - mean salinity at Winnejup (gauge 609012) in the upper catchment (Figure 60), between 1993 and 2002, was 4700 mg/L TDS, whereas it was 2100 mg/L TDS at Hut Pool (609019) in the lower catchment during the same period (Mayer et al. 2005).

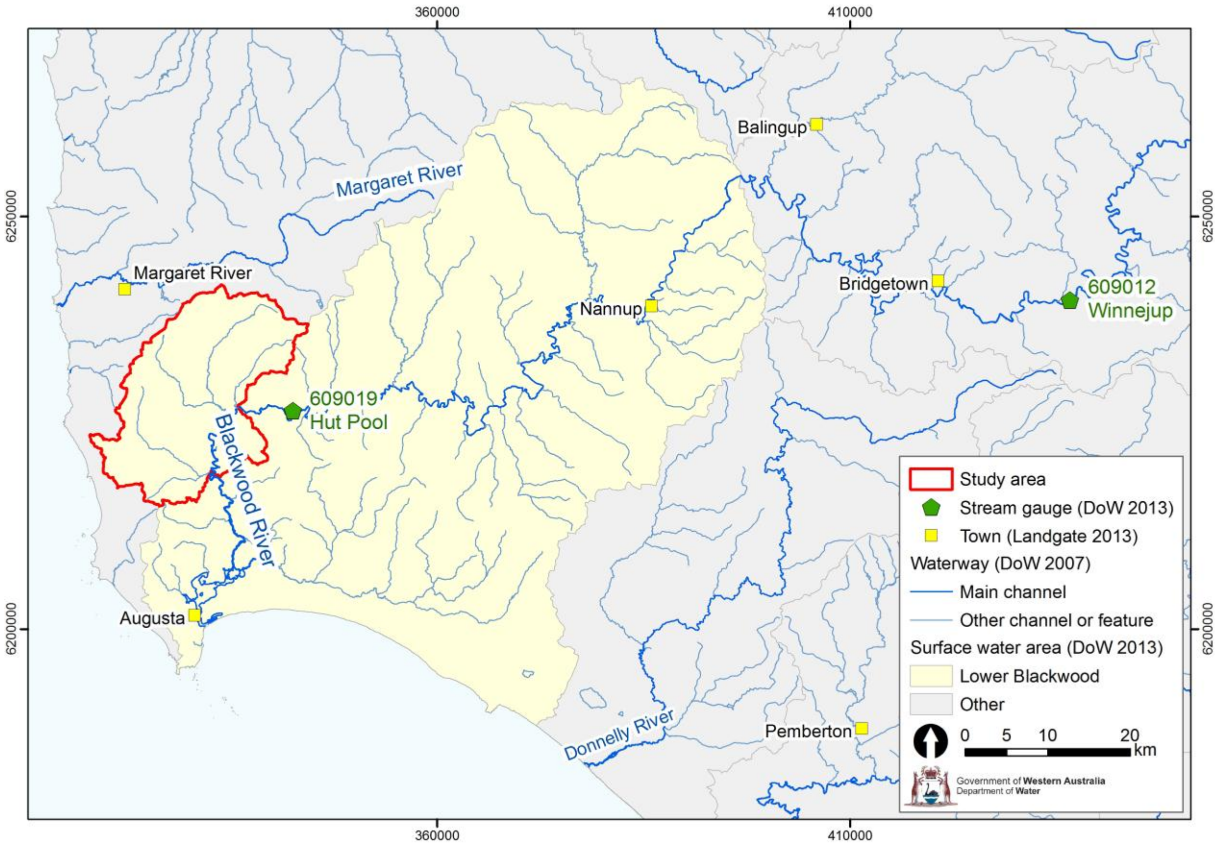


Figure 60 Stream flow gauging stations on the lower Blackwood River

The salinity concentration measured at site BLA16X in February 2013 was 179 mg/L TDS (fresh) which indicates the tributary inputs fresh water into the Blackwood River between sites BLA15 and BLA16. Further sampling is required to determine the seasonal variation in flow and salinity of the tributary.

5.6.6 Theme: aquatic biota

Aquatic biota were not assessed at these sites.

6 Conclusions

Through the application of the South West Index of River Condition (SWIRC), this study has:

- provided an assessment of river health that will serve as a baseline against which future change can be measured
- provided river health data to support the development of a river action plan for the McLeod and Rushy creeks
- provided data (and established river health monitoring sites for future assessment) to support allocation decisions and contribute to the Stage 2 Water quality improvement plan (WQIP) for the Hardy Inlet (DoW in prep).

Further, the data can be included in the ecological character description for the proposed nomination of the lower Blackwood River area as a wetland under the Convention on Wetlands of International Importance (known as the Ramsar convention) (Strehlow & Cook 2010). They can also provide a baseline for indicators of change within any management plans developed for the proposed Ramsar wetland area and the lower Blackwood River high ecological value aquatic ecosystem (HEVAE).

Overall, the ecological health of the waterways assessed was good, with the majority of SWIRC theme scores for each system being in the top two condition bands (largely unmodified and slightly modified).

The ecological values found during this study support the identification of the lower Blackwood River HEVAE. The key ecological values are summarised below (for an extended summary see Appendix Y).

- The fish and crayfish community in the study area comprised 13 native fish and crayfish species, 11 of which are endemic to south-west Western Australia.
- The community included:
    - one Threatened species, *G. munda*, (listed under the *Wildlife Conservation Act 1950,* DPaW 2013), which was found across seven sites in the McLeod and Fisher creeks and Upper Chapman Brook, and
    - one Priority 1 species (poorly known species on threatened lands), *G. australis*, (listed by DPaW 2013) found in Upper Chapman Brook.
- Fish and crayfish species richness per site was high for south-west Western Australia, with six or more native species present at over half the sites (it is rare to find more than six species at any one site (Storer et al. 2011b)). In particular, a high native species richness was found in McLeod Creek at sites MCLEOD (nine native species) and MC10 (seven native species) in October 2012, and in Upper Chapman Brook at site UCHAP5 (seven native species) in February 2013.
- The presence of juvenile fish at sites in McLeod, Rushy and Fisher creeks and Upper Chapman Brook suggests these systems may be nursery areas for fish and crayfish species.

- Evidence of reproductive condition in fish species suggested the presence of spawning areas in McLeod and Fisher creeks and Upper Chapman Brook (these areas may also occur in Chapman Brook and Rushy Creek, but were not observed during this study).
- The Fisher Creek site, FISHX3, was the only site where juvenile *G. munda* were recorded, and this included the presence of post-larvae sized individuals – suggesting a recent spawning event. Given that *G. munda* is listed as a Threatened species under the *Wildlife Conservation Act 1950* (DPaW 2013), protection of the spawning habitat is important.
- Potential summer refugia were identified in McLeod Creek and Upper Chapman Brook, including the lower reaches of McLeod Creek, which Beatty et al. (2008) suggest acts as a refuge for freshwater species from the tidally influenced waters of the lower Blackwood River. Given the observed and predicted impacts of climate change in south-west Western Australia (see Section 2), the presence, duration and quality of permanent water refugia will become increasingly important to the maintenance of aquatic biodiversity in the area.
- Several notable macroinvertebrate taxa were found in the study area including:
  - two new larval forms of caddisfly larvae across four sites in the study area (McLeod Creek and Upper Chapman Brook)
  - two species of caddisfly larvae described as endangered (Sutcliffe 2003) across four sites (in McLeod, Rushy and Fisher creeks)
  - one species of stonefly larvae with a limited distribution in the south-west (WRM 2009) at one site in McLeod Creek
  - one species of stonefly larvae with Gondwanic affinities (WRM 2009) at two sites in McLeod Creek
  - one species of freshwater mussel, *W. carteri*, at four sites (McLeod Creek and Upper Chapman Brook): this species is listed as Priority 4 (rare, near threatened and other species in need of monitoring) by DPAW (2013).
- Notably, the macroinvertebrate community found in McLeod Creek had a high taxa richness compared with other river systems in south-west Western Australia (Emma van Looij pers. comm. 2013), including one species endemic to the south-west (*R. occidentalis*, WRM 2009) and two species of caddisfly suggested to be endangered by Sutcliffe (2003).
- A high extent of fringing zone (covering >70% length of a reach and >30 m average width on each bank) was found for more than half the study reaches, including the majority of reaches in McLeod Creek (excluding the upper reach, MRAP1), the northern tributary of Rushy Creek (RRAP9), the upper and mid catchment reaches of Upper Chapman Brook (UCHAPX1 and UCHAP6), Fisher Creek and the lower Blackwood River reach.
- Exotic plant species were absent from the tree layers at all sites, along with the shrub and ground cover layers at four sites: the lower site on McLeod Creek (MC10), the upper

site on Upper Chapman Brook, and sites on Fisher Creek and the lower Blackwood River.

- Water quality was generally within the guideline values selected for this study (see Section 3.4.5) in most systems. The non-nutrient contaminants assessed in water and sediment at four sites in Chapman and Upper Chapman brooks were either below guideline levels (bioavailable metals in sediment) or below the current limit of laboratory reporting (organochlorine and organophosphate pesticides in sediment and herbicides in water).

Based on the results of the study, a number of potential threats to aquatic ecological health were identified. Dry conditions were observed at a number of sites in February 2013, with the potential impacts of these conditions being noted in the assessment of aquatic biota. For example, fish and crayfish species richness was generally lower in the upper catchments of all systems, most likely due to drying. Given the lack of historical flow data for these river systems, it is not possible to determine whether the degree of drying is natural (i.e. if the systems are naturally ephemeral), or if the drying – and associated low species richness – reflects an impact of climate change (via reduced streamflow). However, given the projected decline in mean annual rainfall and runoff for the area (see Section 2.4), the presence of permanent water refugia during summer will become increasingly important for aquatic biota.

Other potential threats related to the fringing vegetation and physical form of the systems are summarised below (see Appendix Y for a full summary):

- The extent of the fringing zone was low (covering <70% length of a reach and <30 m average width on each bank) for just under half the study reaches, including those in the Chapman Brook, the majority of Rushy Creek, the northern tributary and mid catchment of Upper Chapman Brook and the upper reach of McLeod Creek.
- A high proportion (>50% cover) of exotic plant species was found in the ground cover layer at six sites: the upper McLeod Creek site, the northern tributary and lower catchment sites of Rushy Creek, and the mid catchment and northern tributary sites of Upper Chapman Brook.
- The extent of erosion was moderate to high (between 21 and 100% of site length) at three sites clustered in the lower catchment of Rushy Creek, and at two sites in the mid catchment of Upper Chapman Brook.
- The combined cover of shrub and tree vegetation in the streamside zone (a proxy for bank stabilisation) was sparse at the northern tributary and lower main channel sites of Rushy Creek. Three sites in the southern tributary and lower catchment of McLeod Creek had a dense shrub layer but sparse to absent tree layers (MRAP8, MCLEOD and MC10). These sites may be vulnerable to erosion, given the reduced cover of streamside vegetation stabilising the banks.
- A number of possible minor dams were identified on the majority of reaches (14 out of 18 reaches) using desktop data analysis. Site investigation is required to confirm whether these structures are present, and to quantify their impact – if any – on biota passage and other aspects of longitudinal connectivity such as sediment flushing and transport.

Further, the exceedences of water quality guidelines for two parameters may warrant further investigation as outlined below:

- Total nitrogen exceeded the guideline value selected for this study (see Section 3.4.5) in eight of 34 samples. Given these were snapshot samples, further sampling at a greater spatial and temporal resolution is required to establish variability in total nitrogen concentrations in the study area.
- Dissolved oxygen was below the guideline value selected for this study (see Section 3.4.5) for a substantial period of time (>12 hours) at two sites (MRAP1 and UCHAPX2). Further investigation is required to determine the temporal and spatial variability in dissolved oxygen at these sites, and the subsequent risk to aquatic biota.

In summary, a number of ecological values were identified in the study area, including high native species richness and endemism, and nursery and spawning areas for fish and crayfish. These values were found across the study area, including at sites where potential threats, such as reduced fringing vegetation and extensive erosion, were identified. Given the aquatic biota index scores were in the top two condition bands for the majority of sites, including those with lower scores for the fringing zone and physical form indices, this suggests the aquatic biota community has sufficient resilience to withstand these pressures at present. However, this resilience may not continue in the future, thus consideration should be given to further investigation and management of these potential threats to aquatic ecosystem health.

As with any short-term monitoring program, the data analysis and SWIRC scores presented in this study represent a snapshot of the ecological health of the river systems at a given point in time – accordingly some values and threats may remain undetected. The results form a baseline for more detailed, targeted assessment (see Section 7 Knowledge gaps).

7 Knowledge gaps

Several knowledge gaps were identified during the course of the study:

Hydrological change

There is a lack of flow data for the Rushy, McLeod and Fisher creeks, and temporally limited data for the Upper Chapman Brook. As a result it is difficult to develop an understanding of the flow regime of these areas, including elements of the low flow, high flow, period of zero flow and seasonality. Installation of temporary gauges, and the development of stage-discharge curves, would support understanding the flow regime and any impacts of climate change on these systems. Further, if detailed flow regime data were available, the impact of farm dams on the seasonal flow regime could be clarified (e.g. to determine how the impoundment of water from summer and early autumn rainfall events influences the flow regime in the creeks and brooks during this period).

During the course of the field sampling conducted in February 2013, it became clear that flow had ceased at a number of the study sites in the Chapman and Upper Chapman brooks and McLeod Creek. Some ad-hoc observations of water depth and flow were made at various locations, however a comprehensive survey of each system is suggested to determine the location, duration and quality of permanent water refugia during the summer months. In addition, snapshot discharge measurements at areas of interest throughout the catchments would provide information on the summer flow regime, which would help to determine any areas of permanent flow.

Fringing vegetation

The desktop method used to assess the extent of fringing vegetation provides a rapid initial assessment at a reach scale. Given the inherent issues of accuracy with spatial data – accuracy is generally dictated by the purpose for which the data was collected rather than subsequent use – the results provide a first-pass, broad indication of areas where fringing vegetation is limited or absent. Targeted site-specific assessment may be required to provide further detail in areas of interest.

At present, the fringing zone index does not include a reach-scale assessment of the condition of plants within the riparian zone; the use of remotely sensed data such as the normalised difference vegetation index (NDVI) could be investigated to provide a measure of vegetation condition. Alternatively, on-ground surveys of vegetation condition could be considered for future assessments.

Physical form

The desktop method used to assess longitudinal connectivity provides a rapid initial assessment at a reach scale, and uses a dataset of potential structures (dams, road crossings) that may act as a barrier to biota movement. It is recommended that the potential structures are ground-truthed to confirm their presence or absence. If present, the extent to which they present a barrier to biota movement should be assessed, along with any impacts on other aspects of connectivity (e.g. sediment transport).

Water quality

Although water quality parameters were generally within guidelines, a number of exceedences occurred. Given that a maximum of three samples were taken at each site, over three seasons, it is not possible to determine whether these exceedences were single events or reflect long-term elevated concentrations. Regular monitoring for several years is recommended to determine the seasonal variability in water quality.

Aquatic biota

The macroinvertebrate results presented in this report are from a single sampling occasion in October 2012. As such, the results are a snapshot of the communities present and caution should be applied when interpreting the data. Taxa richness, for example, is likely to vary temporally, hence a single sample will significantly underestimate taxa richness compared with multiple samples taken over a period of time. A better understanding of the macroinvertebrate fauna in the study area would be achieved by sampling for several years.

Two new larval forms of Notoperata (caddisfly larvae) were collected during this study; these larval forms have not previously been described. Further work, such as rearing live larvae to the adult form for identification, or using deoxyribonucleic acid (DNA) techniques, are required to determine if these are undescribed larval forms of known caddisfly species, or if they are completely new species (Rosalind St Clair pers. comm. 2013).

A large number of cormorants (more than 100) were observed around the dam on the Rushy Creek; further work is required to determine how the predatory pressure of these birds affects the fish and crayfish population of Rushy Creek, particularly given that species may congregate in the dam during summer if other permanent water refugia are not available.

Appendices

Appendix A — Maps of on-ground works

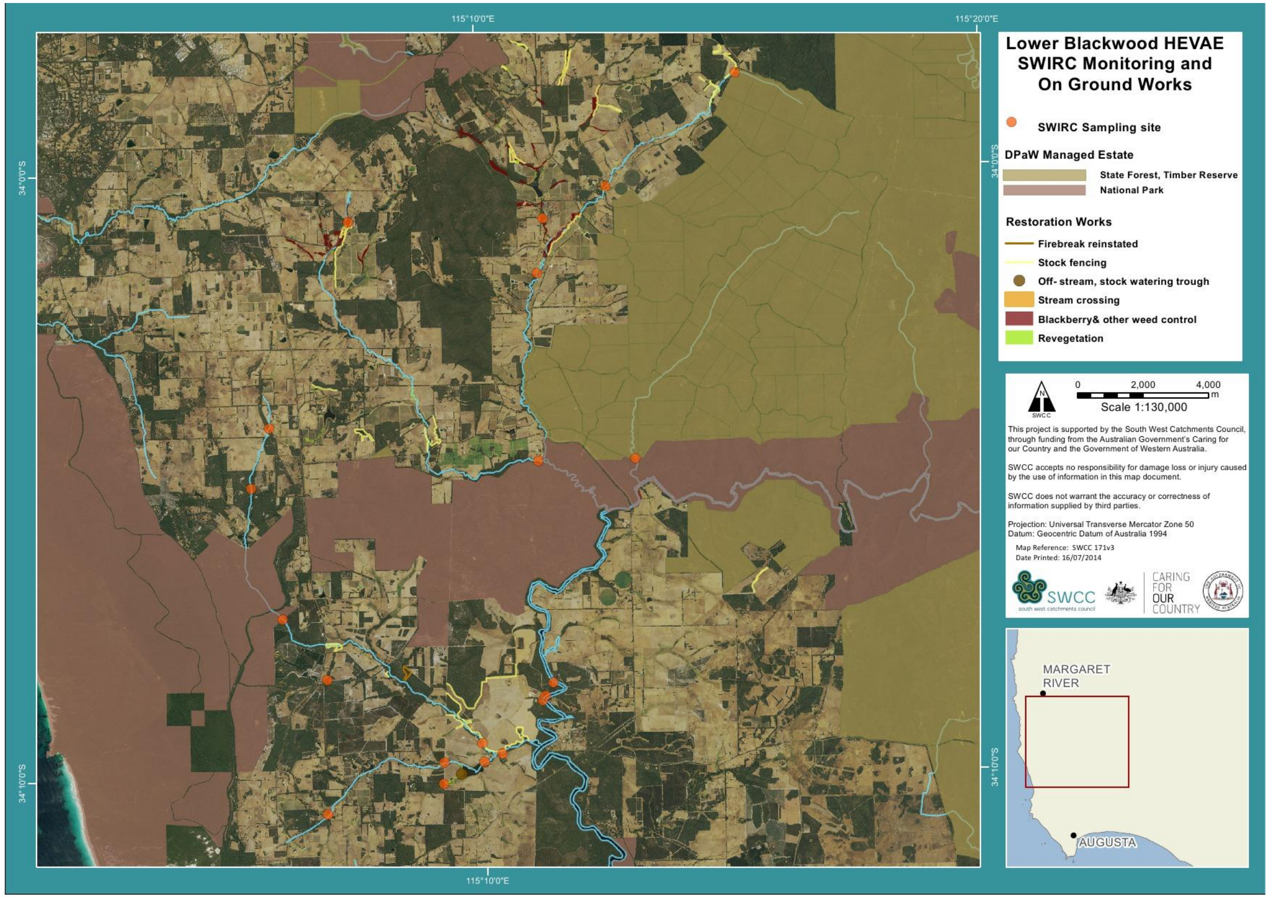


Figure A1 Overview of on-ground works (Source: South West Catchments Council)

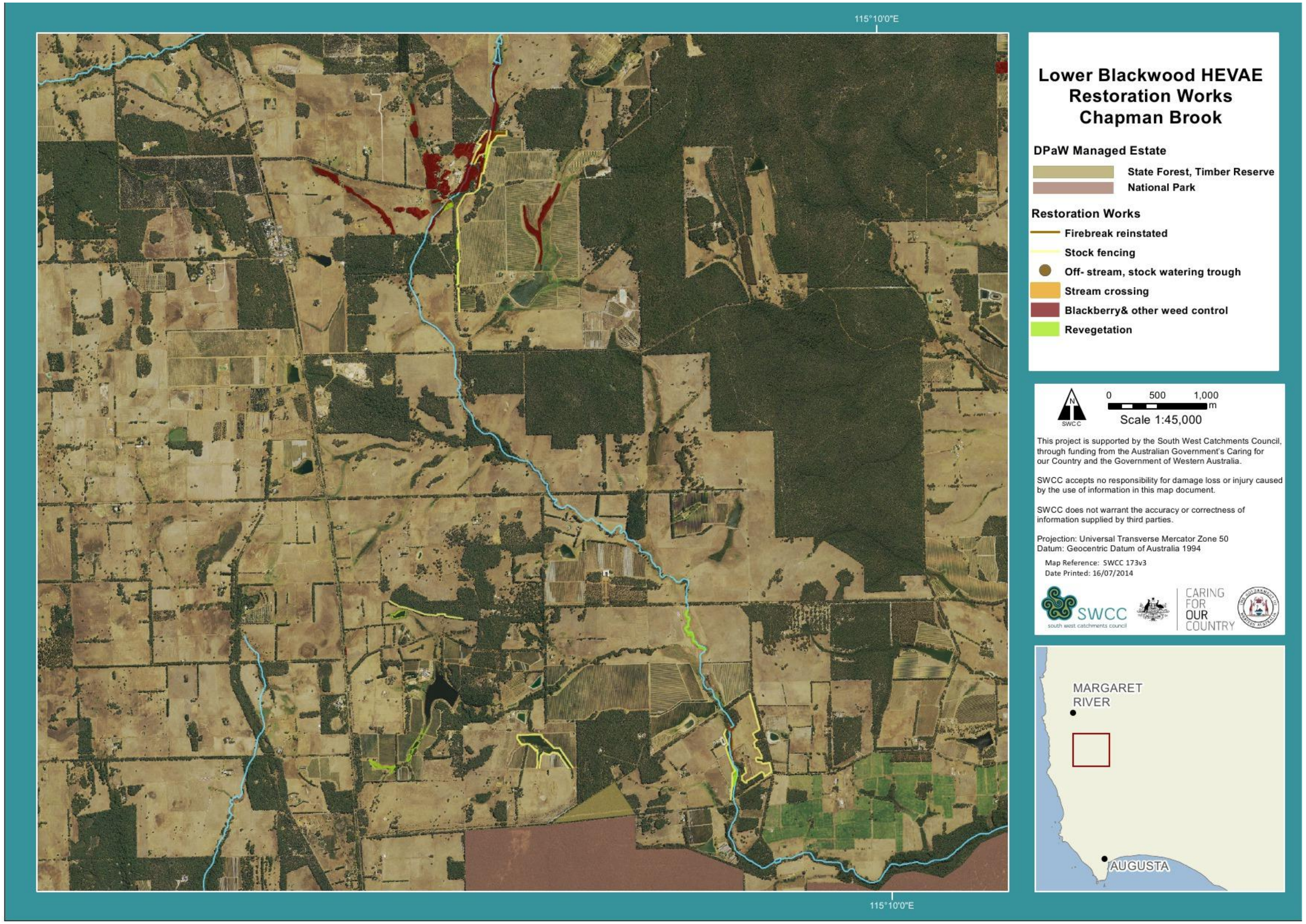


Figure A2 On-ground works – Chapman Brook (Source: South West Catchments Council)

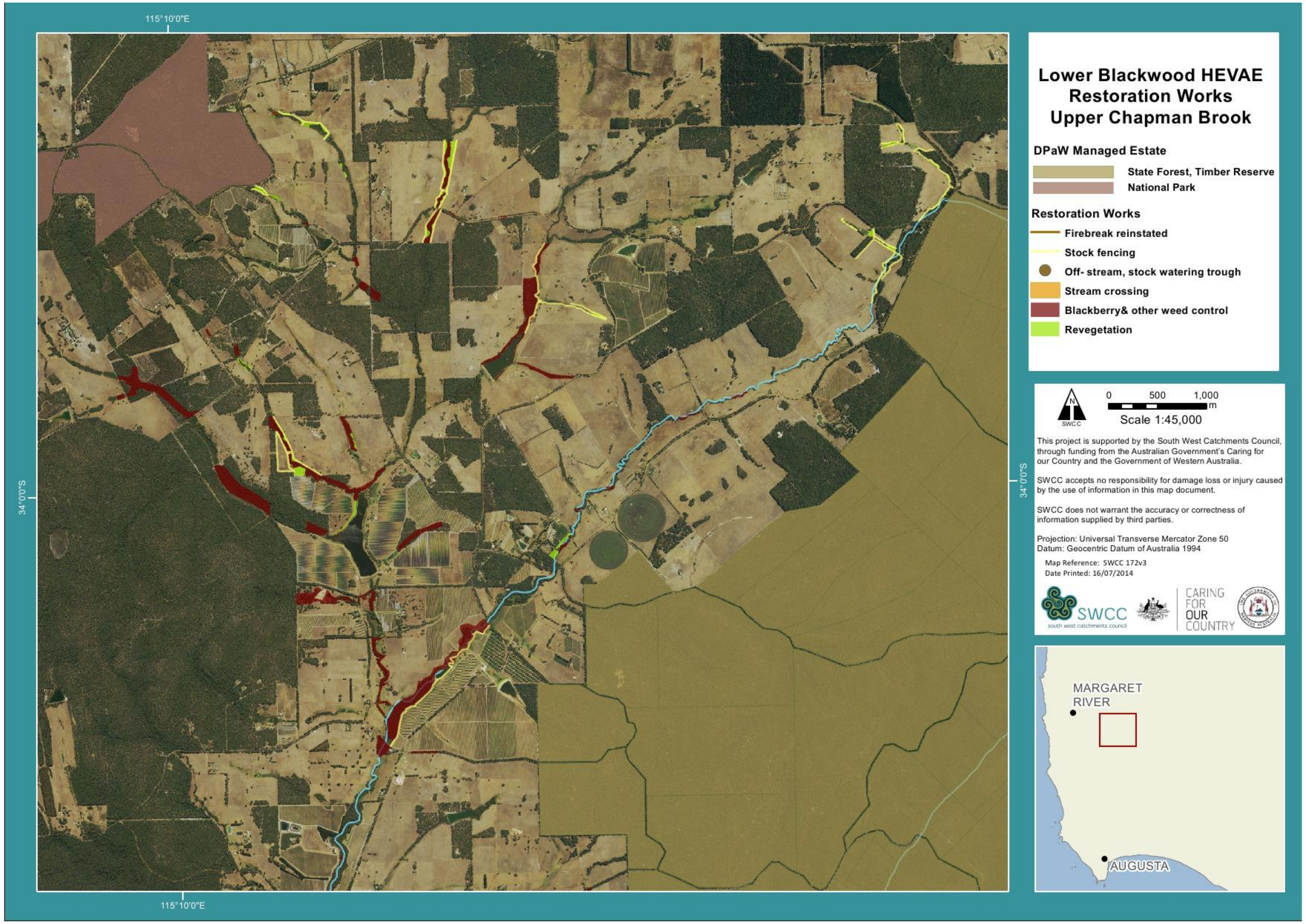


Figure A3 On-ground works – Upper Chapman Brook (Source: South West Catchments Council)

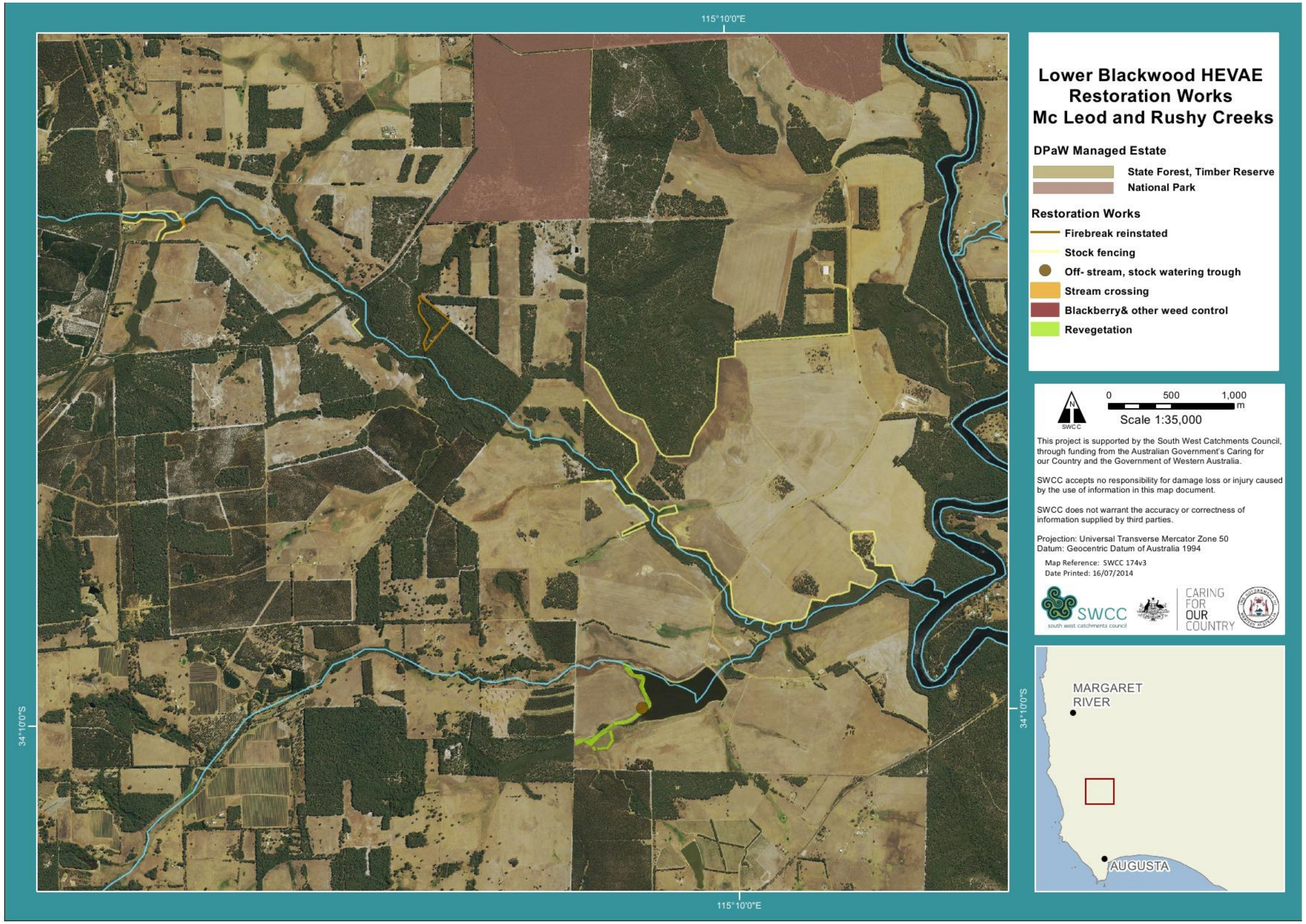


Figure A4 On-ground works – McLeod Creek (Source: South West Catchments Council)

Appendix B —Threatened and Priority fauna, flora and ecological communities in the study area

Table B1 Threatened and Priority fauna occurring in the study area

Class	Name	Common name	Conservation status code	Conservation status description
Amphibian	*Geocrinia alba*	White-bellied frog	T	Threatened (fauna that is rare or is likely to become extinct)
Fish	*Galaxiella munda*	Western mud minnow	T	Threatened (fauna that is rare or is likely to become extinct)
Bird	*Calidris ferruginea*	Curlew sandpiper	T	Threatened (fauna that is rare or is likely to become extinct)
Bird	*Calyptorhynchus banksii subsp. naso*	Forest red-tailed black-cockatoo	T	Threatened (fauna that is rare or is likely to become extinct)
Bird	*Calyptorhynchus baudinii*	Baudin's cockatoo (long-billed black-cockatoo)	T	Threatened (fauna that is rare or is likely to become extinct)
Bird	*Calyptorhynchus latirostris*	Carnaby's cockatoo (short-billed black-cockatoo)	T	Threatened (fauna that is rare or is likely to become extinct)
Bird	*Numenius madagascariensis*	Eastern curlew	T	Threatened (fauna that is rare or is likely to become extinct)
Bird	*Falco peregrinus*	Peregrine falcon	S	Other specially protected fauna
Bird	*Actitis hypoleucos*	Common sandpiper	IA	Birds protected under an international agreement
Bird	*Ardea modesta*	Eastern great egret	IA	Birds protected under an international agreement
Bird	*Calidris ruficollis*	Red-necked stint	IA	Birds protected under an international agreement
Bird	*Egretta sacra*	Eastern reef egret, eastern reef heron	IA	Birds protected under an international agreement
Bird	*Haliaeetus leucogaster*	White-bellied sea-eagle	IA	Birds protected under an international agreement
Bird	*Limosa lapponica*	Bar-tailed godwit	IA	Birds protected under an international agreement
Bird	*Limosa limosa*	Black-tailed godwit	IA	Birds protected under an international agreement
Bird	*Merops ornatus*	Rainbow bee-eater	IA	Birds protected under an international agreement

Class	Name	Common name	Conservation status code	Conservation status description
Bird	*Onychoprion anaethetus*	Bridled tern	IA	Birds protected under an international agreement
Bird	*Plegadis falcinellus*	Glossy ibis	IA	Birds protected under an international agreement
Bird	*Tyto novaehollandiae* subsp. *novaehollandiae*	Masked owl (southern subsp)	3	Priority 3: Poorly known taxa
Bird	*Burhinus grallarius*	Bush stone-curlew	4	Priority 4: Rare, Near Threatened and other taxa in need of monitoring
Bird	*Falcunculus frontatus* subsp. *leucogaster*	Western shrike-tit, crested shrike-tit	4	Priority 4: Rare, Near Threatened and other taxa in need of monitoring
Mammal	*Bettongia penicillata* subsp. *ogilbyi*	Woylie, brush-tailed bettong	T	Threatened (fauna that is rare or is likely to become extinct)
Mammal	*Dasyurus geoffroii*	Chuditch, western quoll	T	Threatened (fauna that is rare or is likely to become extinct)
Mammal	*Petrogale lateralis* subsp. *lateralis*	Black-flanked rock-wallaby, black-footed rock-wallaby	T	Threatened (fauna that is rare or is likely to become extinct)
Mammal	*Phascogale tapoatafa* subsp. *(WAM M434)*	Brush-tailed phascogale (sw subsp), wambenger	T	Threatened (fauna that is rare or is likely to become extinct)
Mammal	*Phascogale tapoatafa* subsp. *tapoatafa*	Southern brush-tailed phascogale, wambenger	T	Threatened (fauna that is rare or is likely to become extinct)
Mammal	*Potorous gilbertii*	Gilbert's potoroo	T	Threatened (fauna that is rare or is likely to become extinct)
Mammal	*Pseudocheirus occidentalis*	Western ringtail possum	T	Threatened (fauna that is rare or is likely to become extinct)
Mammal	*Pseudomys fieldi*	Shark bay mouse, djoongari	T	Threatened (fauna that is rare or is likely to become extinct)
Mammal	*Pseudomys shortridgei*	Heath mouse, dayang	T	Threatened (fauna that is rare or is likely to become extinct)
Mammal	*Setonix brachyurus*	Quokka	T	Threatened (fauna that is rare or is likely to become extinct)
Mammal	*Hydromys chrysogaster*	Water rat	4	Priority 4: Rare, Near Threatened and other taxa in need of monitoring
Mammal	*Macropus irma*	Western brush wallaby	4	Priority 4: Rare, Near Threatened and other taxa in need of

Class	Name	Common name	Conservation status code	Conservation status description
				monitoring
Mammal	*Isoodon obesulus* subsp. *fusciventer*	Quenda, southern brown bandicoot	5	Priority 5: Conservation dependent taxa
Mammal	*Macropus eugenii* subsp. *derbianus*	Tammar wallaby (WA subsp)	5	Priority 5: Conservation dependent taxa

Source: Department of Parks and Wildlife, Threatened Fauna database, data provided 17 May 2013 (reference 2013/000283 #4537).

Table B2 *Threatened and Priority flora occurring in the study area*

Family	Taxon	Description (if available in Western Australian Herbarium (1998–)	Conservation status code	Conservation status description	Threatened and Priority flora database	WA Herbarium database
Cyperaceae–sedge family	*Reedia spathacea*	Robust, tufted perennial, grass-like or herb (sedge), 2–4 m high, clumps 1.5–2 m wide	T	Threatened flora (declared rare flora – extant)	✓	✓
Cyperaceae–sedge family	*Tetraria* sp. *Nannup (P.A. Jurjevich 1133)*	None available	1	Priority 1: poorly known species		✓
Proteaceae–banksia family	*Synaphea* sp. *Redgate Road (J. Scott 16)*	Compact, spreading shrub, to 0.5 m high to 0.5 m wide	1	Priority 1: poorly known species		✓
Orchidaceae–orchid family	*Caladenia* sp. *Boranup (M. Spencer MS71)*	None available	2	Priority 2: poorly known species		✓
Poaceae–grass family	*Austrostipa mundula*	None available	2	Priority 2: poorly known species		✓
Apiaceae–carrot family	*Actinotus* sp. *Walpole* (J.R. Wheeler & S.J. Patrick 3786) PN	None available	3	Priority 3: poorly known species	✓	✓
Cyperaceae–sedge family	*Tetraria* sp. *Blackwood River* (A.R. Annels 3043)	None available	3	Priority 3: poorly known species		✓
Fabaceae–legume, pea or bean family	*Acacia inops*	Weak, scrambling, pungent shrub, 0.4–1.1 m high	3	Priority 3: poorly known species	✓	✓
Fabaceae–legume, pea or bean family	*Acacia subracemosa*	Spreading shrub, 1.8–5 m high	3	Priority 3: poorly known species	✓	✓
Myrtaceae–myrtle family	*Calothamnus lateralis* var. *crassus*	None available	3	Priority 3: poorly known species		✓
Proteaceae–banksia	*Conospermum*	Spreading, open shrub, 0.3–	3	Priority 3: poorly	✓	✓

Family	Taxon	Description (if available in Western Australian Herbarium (1998–)	Conservation status code	Conservation status description	Threatened and Priority flora database	WA Herbarium database
family	*paniculatum*	1.25 m high		known species		
Proteaceae–banksia family	*Grevillea bronwenae*	Slender, erect shrub, 0.5–1.6 m high	3	Priority 3: poorly known species		✓
Restionaceae–restio family	*Meeboldina thysanantha*	Rhizomatous, perennial, herb (rush-like), 0.4–1 m high	3	Priority 3: poorly known species	✓	✓
Thymelaeaceae–daphne family	*Pimelea astrop* subsp. *longituba*	Erect shrub, 0.3–1 m high	3	Priority 3: poorly known species		✓
Ericaceae –heather family	*Astroloma* sp. *Nannup* (R.D.Royce 3978)	none available	4	Priority 4: rare, near threatened and other species in need of monitoring	✓	✓
Fabaceae–legume, pea or bean family	*Acacia semitrullata*	Slender, erect, pungent shrub, (0.1-)0.2-0.7(-1.5) m high	4	Priority 4: rare, near threatened and other species in need of monitoring		✓
Fabaceae –legume, pea or bean family	*Acacia tayloriana*	Prostrate shrub	4	Priority 4: rare, near threatened and other species in need of monitoring		✓
Fabaceae–legume, pea or bean family	*Bossiaea disticha*	Erect or straggly to spreading shrub, 0.1–1.5 m high	4	Priority 4: rare, near threatened and other species in need of monitoring	✓	✓
Myrtaceae–myrtle family	*Chamelaucium* sp. *Yoongarillup* (G.J. Keighery 3635)	None available	4	Priority 4: rare, near threatened and other species in need of monitoring	✓	

Family	Taxon	Description (if available in Western Australian Herbarium (1998–)	Conservation status code	Conservation status description	Threatened and Priority flora database	WA Herbarium database
Myrtaceae–myrtle family	*Eucalyptus calcicola* subsp. *Calcicola*	Mallee or tree, to 4 m high, bark smooth, grey	4	Priority 4: rare, near threatened and other species in need of monitoring	✓	✓

Sources: Department of Parks and Wildlife, Threatened (Declared Rare) and Priority Flora database and the Western Australian Herbarium Specimen, data provided 23 May 2013 (reference 47-0513FL). Note:

- *The Threatened and Priority Flora Database (TPFL) – data provided consists of validated populations of Declared Rare flora and some Priority flora. These records are taken from mostly from Rare Flora Report Forms and WA Herbarium records.*
- *The WA Herbarium (WAHERB) – data provided consists of all records of Declared Rare and Priority species from the WA Herbarium's collection of specimens, and includes un-validated historical specimens, which gives an indication of potential flora, plus reasonable coverage of the Priority flora.*

Table B3 Threatened and Priority ecological communities occurring in the study area

Community ID	Community name	Category of threat
Reedia swamps – Blackwood Plateau	*Reedia spathacea – Empodisma gracillimum – Sporadanthus rivularis* dominated floodplains and paluslopes of the Blackwood Plateau.	Priority 1 – Poorly known taxa
Caves Leeuwin 04	Aquatic Root Mat Community Number 4 of Caves of the Leeuwin Naturaliste Ridge	Critically Endangered – considered to be facing an extremely high risk of extinction in the wild.

Sources: Department of Parks and Wildlife, Threatened Ecological Communities database, data provided 22 May 2013 (reference 10-0513EC).

Appendix C — Photographs of sampling sites

McLeod Creek, October 2012

MRAP1

MRAP2

MC02

MRAP8

MCLEOD

MC10

Rushy Creek, October 2012

RRAP9

RRAP6

RRAP10

RUSHYCK

Chapman Brook, October 2012

CHAP12

CHAPX1

Upper Chapman Brook, October 2012

UCHAP1

UCHAPX2

UCHAP5

UCHAP6

Fisher Creek, October 2012

FISHX3

Blackwood River

BLA15, October 2012

BLA16, February 2013

BLA16X, February 2013

Appendix D — SWIRC field sheets

Date ______________ Site code ______________ Government of Western Australia Department of Water

SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
COVER SHEET

SITE CODE ________________

SWMA ________________

RIVER SYSTEM ________________

RIVER/STREAM NAME ________________

SITE NAME ________________

DATE ____________ COC ____________ SAMPLE NUMBER ____________

NAME OF SAMPLERS ________________

NOT ASSESSED IN FIELD

ALTITUDE ______ (m) SLOPE ______ (m/km) DFS ______ (km) STREAM ORDER ______ (km)

NEAREST RAINFALL STATION ______ (name) DISTANCE AWAY ______ km AVERAGE ANNUAL RAINFALL ______ (mm)

FLOW PATTERN CATEGORY ____________ DISCHARGE CATEGORY ______ (mm)

ORDER OF SAMPLING – DAY 1

1. Take water quality samples: grab followed by in-situ
2. Collect macroinvertebrates
3. Deploy water quality loggers. *Note: after loggers have been deployed only enter river downstream.*
4. Process macroinvertebrate sample
5. Deploy fish/crayfish traps and fyke nets
6. Site photos (important to capture conditions on first day as factors such as water level and flow can change rapidly)
7. Field sheets (if time permits)

ORDER OF SAMPLING – DAY 2

1. Collect fish/crayfish traps and fyke nets
2. Collect water quality loggers: after 25 hours (144 logged measurements)
3. Complete field sheets
4. Complete site photos: fill-in checklist below.

Photo checklist

[ ] Upstream and downstream photos; taken at the top, middle and bottom of the 100m sampling site (6 photos total)
[ ] Representative site photos
[ ] Macroinvertebrate sampling area
[ ] Representative video taken
[ ] Canopy shots (taken from edge of stream of both sides – representative of density of canopy throughout site)

Acronyms
LB: Left Bank, **RB:** Right Bank

Version 12 - November 2009 Page 1 of 19

Date ______________ Site code ______________

Government of Western Australia
Department of Water

SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS

GPS DATUM ______________

LONGITUDE (°E) or EASTING ______________

LATITUDE (°S) or NORTHING ______________

MAP NAME and YEAR OF PUBLICATION ______________ SCALE ______________

PAGE REFERENCE OR MAP NUMBER ______________

ACCESS DETAILS ______________

____

____

____

PROPERTY OWNER ______________

PHONE NUMBER ______________

ADDRESS ______________

NOTIFY BEFORE EACH VISIT [ ] Yes [ ] No PERMISSION REQUIRED [ ] Yes [ ] No

KEY REQUIRED [ ] Yes [ ] No KEY NUMBER / AVAILABLE FROM ______________

ACCESS MAP – SKETCH ROUTE BELOW OR ATTACH MAP TO BACK OF FIELD SHEET

Include flow direction, site location, roads, crossings, north arrow, distances and landmarks.

MAP ATTACHED ☐

Version 12 - November 2009

Page 2 of 19

Date ________________ Site code ________________

Government of Western Australia
Department of Water

SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
GENERAL SITE ASSESSMENT – 100m sampling site

Artists name ______________________________

LONGITUDINAL DIAGRAM (AERIAL VIEW)

Essential features	Legend
Flow direction	→ → →
Loggers	(L)
Macroinvertebrate sample	(M)
Water quality sample	(W)
Fyke nets	▶ or ◀
North arrow	↑ N

Possible features	DIY legend	*Possible features*	DIY legend
Macrophyte habitat		Vegetation type A: ____________	
Large trees		Vegetation type B: ____________	
Woody debris		Vegetation type C: ____________	
Riffles			
Sandbars/sediment deposits			
Significant erosion			
Natural or artificial barriers			

Version 12 - November 2009

Page 3 of 19

Date ________________ Site code ________________

Government of Western Australia
Department of Water

SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
GENERAL SITE ASSESSMENT – 100m sampling site

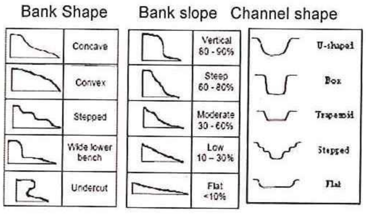
CROSS SECTION DIAGRAM

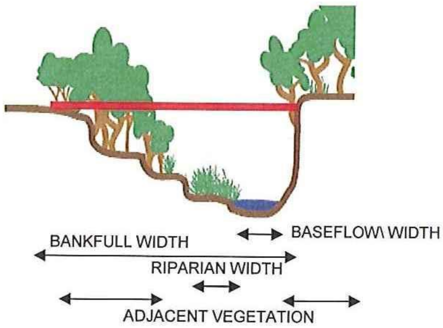
Representative of sampling region (where high variability exists draw two cross-sections).

Suggested information to include on cross section diagram above

- Bank shape (see below)
- Bank slope (see below)
- Channel shape (see below)
- Base-flow and bank-full width (m)
- Streamside and adjacent vegetation width and structure
- Presence of bars, benches, toes

Circle diagrams below





STREAM WIDTH MEASURMENTS

	Top	Middle	Bottom
Bankfull width (m)	______	______	______
Current water width (m)	______	______	______

Water width compared to base-flow (circle)				
No flow dry isolated	Low < low water mark	Moderate Equal to base-flow	High > high water mark	Flood

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
AQUATIC HABITAT ASSESSMENT – 100m sampling site

STREAM HABITAT DIVERSITY

Habitat area	%
Channel (Includes woody debris)	
Macrophytes	
Riffle	
Pool	
Total	100

Macrophyte types	%
Emergent	
Submerged	
Floating	
Total	100

Large woody debris ☐ present ☐ absent (*Size relative to 'un-impacted' conditions for specific area*)	
Diversity (circle)	**Abundance** (circle) *
Wood of similar size	Sparse (few pieces)
2-3 different sizes	Moderate *
Variety of sizes	Dense (throughout most of site)

* A few sections of moderate density or low density across most of site

Bank vegetation draped in water ** (percentage of bank length)	

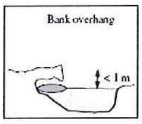
Note: section relates to habitat (not shading). ** *Dead vegetation not included*

Roots overhanging and draped in water			
None	Limited	Moderate	Extensive
Overhanging banks			
None	Limited	Moderate	Extensive

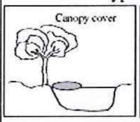
Limited = 1-10% of bank length, Moderate = 11-50%, Extensive >50% of bank.

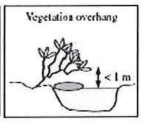
Flow (circle)
Uniform flow (e.g. drain)
Moderately varied flow
Varied flow (eg eddies, backwaters, fast, slow)

Depth (circle)
Uniform depth (eg drain)
Moderately varied depth
Varied depths



Stream shading	Percentage of bank length		Average distance from bank (m) Average stream width ________ m	
	LB	RB	LB	RB
Tree cover #				
Shrub overhang				
Grass overhang (rushes/sedges)				





\# Note: density of canopy will be determined from canopy photographs; therefore only total area should be assessed.

Physical substrate DIVERSITY	Increasing complexity (circle one number)
Mainly bedrock or artificial substrate	1 2 3 4 5
Silt or sand or a mixture of silt and sand	6 7 8 9 10
Mainly sand with some pebbles &/or boulders	11 12 13 14 15
Mix of boulders, pebbles & sand etc	16 17 18 19 20

Note: increasing complexity or density are not a direct indication of health (i.e. boulders are not expected at all sites)

Biological substrate DENSITY *Tip: try breaking site into sub-sections (i.e. 10 x 10m sections for a 100m sampling site), to estimate cover*	Increasing density (circle one number)
<10% of substrate cover	0 1 2 3 4 5
11-30%	6 7 8 9 10
31-60%	11 12 13 4 15
>60%	16 17 18 19 20

Biological substrate DIVERSITY (circle)				
leaves	twigs	branches	detritus *	Epiphytes

* *Detritus relates to undifferentiated organic material*

Sediment deposition	None or minor	Not obvious	Obvious

Type (sand/silt): ______________________________

WATER AND SEDIMENT

Circle the appropriate description under each category.

Water odours	*Water Oils*	*Turbidity*	*Tannin staining* *	*Algae in water column*	*Algae on substrate*	*Plume***	*Sediment oils*	*Sediment odours*
Normal/None	None	Clear	Clear	0%	0%	Small	Absent	Normal/None
Anaerobic	Slick	Slight	Slight	1 to 10%	1 to 10%	Moderate	Light	Sewage
Sewage	Sheen	Turbid	Light tea	11 to 50%	11 to 50%	Large	Moderate	Petroleum
Petroleum	Globs	Opaque	Dark tea	51 to 75%	51 to 75%		Profuse	Chemical
Chemical	Flecks		Black	> 75%	> 75%			Anaerobic

* tannin staining can be confused when combined with systems containing fine suspended sediment (if problematic assess from filtered water sample)
** relates to amount of fine sediment generated and time take to settle (i.e. a large plume may extend for a meter diameter and remain suspended for 5 seconds or more)

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SW-WA RIVER HEALTH ASSESSMENT – FIELD SHEETS
PHYSICAL FORM/CATCHMENT IMPACT ASSESSMENT – 100m sampling site

BANKS AND PHYSICAL FORM

AMOUNT of erosion Length of bank affected (%)		
0 to 5%	LB	RB
>5 to 20%	LB	RB
21 to 50%	LB	RB
> 50%	LB	RB

SEVERITY of erosion, and bank stability	Circle	
Severe: LITTLE TO NO STRUCTURAL INTEGRITY Banks are predominantly bare. Significant sections of erosion (undercutting/slumping) on both outside bends and straight stretches (sediment deposits in river). Exposed roots obvious (where applicable), with significant loss of vegetation in eroding areas. Channel shape, bank shape and depth likely to change in near future.	LB	RB
High: POOR STRUCTURAL INTEGRITY Evidence of bank instability (undercutting/slumping); with signs of soil loss from banks, and possibly areas of sedimentation (i.e. sandbars or toes) and scouring. Some exposed roots (where applicable), with loss of vegetation in eroding areas. Erosion typically around outside bends.	LB	RB
Low-Moderate: GOOD STRUCTURAL INTEGRITY Banks relatively stable – exposed and superficially eroding bank (erosion doesn't penetrate deeply into bank wall) or stabilised by only exotic grasses. Little likelihood of significant change to channel/bank shape, depth or loss of bank material in near future.	LB	RB
Minor: EXCELLENT STRUCTURAL INTEGRITY Banks stable and mostly intact (minor slumping, undercutting or bare banks expected naturally): stabilised by vegetation or bedrock.	LB	RB

Factors affecting bank stability	Circle	
Feral animals	LB	RB
Livestock access (if yes, compete table below)	LB	RB
Human access	LB	RB
Cleared vegetation	LB	RB
Runoff		
Irrigation draw-down		
Flow and waves		
Culvert, bridge, dam		
Drain pipes	LB	RB
Other (specify)		

Stabilisation works Yes ☐ No ☐		
Choose one or more	Circle	
Rock wall protection	LB	RB
Bank matting	LB	RB
Logs/planks strapped to bank	LB	RB
Concrete lining	LB	RB
Revegetation plantings	LB	RB
Fenced human access (deterrent)	LB	RB
Fenced livestock access	LB	RB
Fenced stock watering points	LB	RB
Other (specify)	LB	RB

Indicate livestock types ______________________________ & indicate their impact (major or minor) for each category below.

CATEGORY	MINOR	Tick box	MAJOR	Tick box
Vegetation damage	Only small patches of vegetation grazed		Most groundcover vegetation grazed.	
Bank damage	Isolated areas (1 or 2) of livestock damage		Near continuous livestock damage to stream	
Pugging	Isolated (1or 2) areas of pugging		Extensive pugging along the stream length	
Manure	≤2 significant manure deposits per site		>2 significant manure deposits per site	
Tracks	≤1 track per site		>1 track per site	

POLLUTION SOURCES

Local point source pollution		*None evident* ☐
Potential	**Obvious**	**Indicate type/s:**
Within site	Within site	
Upstream	Upstream	
Downstream	Downstream	

Local non-point source pollution		*None evident* ☐
Potential	**Obvious**	**Indicate type/s:**
Within site	Within site	
Upstream	Upstream	
Downstream	Downstream	

LANDUSE AT SITE - WITHIN 50m FROM EDGE OF STREAM

Circle all applicable for each bank

LB	Conservation	Remnant vegetation	Water Catchment	State Forest	Aboriginal Reserve	Vacant. Crown Land	Agriculture	Pastoralism	Tourism	Mining	Industrial	Urban
RB	Conservation	Remnant vegetation	Water Catchment	State Forest	Aboriginal Reserve	Vacant. Crown Land	Agriculture	Pastoralism	Tourism	Mining	Industrial	Urban

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
VEGETATION ASSESSMENT - 100m sampling site

RIPARIAN VEGETATION

Riparian zone = a clear distinction in vegetation type between water dependant and non-water-dependent vegetation

Riparian zone ABSENT ☐ >>>> Due to: **human impact** ☐ **natural feature (eg bedrock)** ☐ **fire/flood…** ☐ **unknown** ☐

Riparian zone PRESENT ☐ [complete rest of box]

Indicate riparian layers PRESENT*?	circle			**Width of riparian zone** Left bank _____m Right bank _____m
Ground layer (i.e. sedges, rushes)	yes	no	reduced	**Dominant riparian species** (if unknown write: refer to photographs):
Shrub layer (woody)	yes	no	reduced	
Tree layer	yes	no	reduced	

* this refers to the presence of riparian species (intactness is incorporated below). Note: if only 1 or 2 shrubs remain (for example) circle 'no'.

STREAMSIDE ZONE VEGETATION (FIRST 10m) - NATIVE AND EXOTIC VEGETATION

Percentage cover	0%		1 - 10%		10 to 50%		50 - 75%		> 75%	
	LB	RB	LB	RB	LB	RB	LB	RB	LB	RB
Bare ground (not bedrock)										
Ground cover/grasses/sedges/rushes										
Shrubs (woody, multi-stem)*										
Trees < 10m										
Trees > 10m										

*Shrubs include Blackberry, Tea trees

STREAMSIDE ZONE VEGETATION (FIRST 10m) - EXOTIC VEGETATION

Proportion (%) of exotic vegetation in each vegetation layer	0%		1 - 10%		10 to 50%		50 - 75%		> 75%	
	LB	RB	LB	RB	LB	RB	LB	RB	LB	RB
Ground cover/grasses/sedges/rushes										
Shrubs (woody, multi-stem)*										
Trees < 10m										
Trees > 10m										

STREAMSIDE ZONE VEGETATION (FIRST 10m) - NATIVE WOODY VEGETATION

Recruitment evidence	*Recruitment type*	*Extent of recruitment*	*Recruitment health*
None	Trees	Limited	Poor
Natural	Shrubs	Moderate	Moderate
Planted	Both	Abundant	Healthy

ADJACENT ZONE VEGETATION (10 to 100m)

Tick box for the DOMINANT feature in each zone	10 to 50m		50 to 100m		100m +	
	LB	RB	LB	RB	LB	RB
Minimal vegetation Typical of areas of urban development / industry / mining						
Weeds/Grasses May have a few scattered trees (typical of agriculture)						
Remnant vegetation Mostly native trees and/or shrubs (may have exotic understorey).						
Forest Native trees, shrubs and understorey. Few or no exotics.						
Plantations **Type:** ______________________________						
Other (describe)						

COMMENTS (VEGETATION IN ADJACENT ZONE): ____

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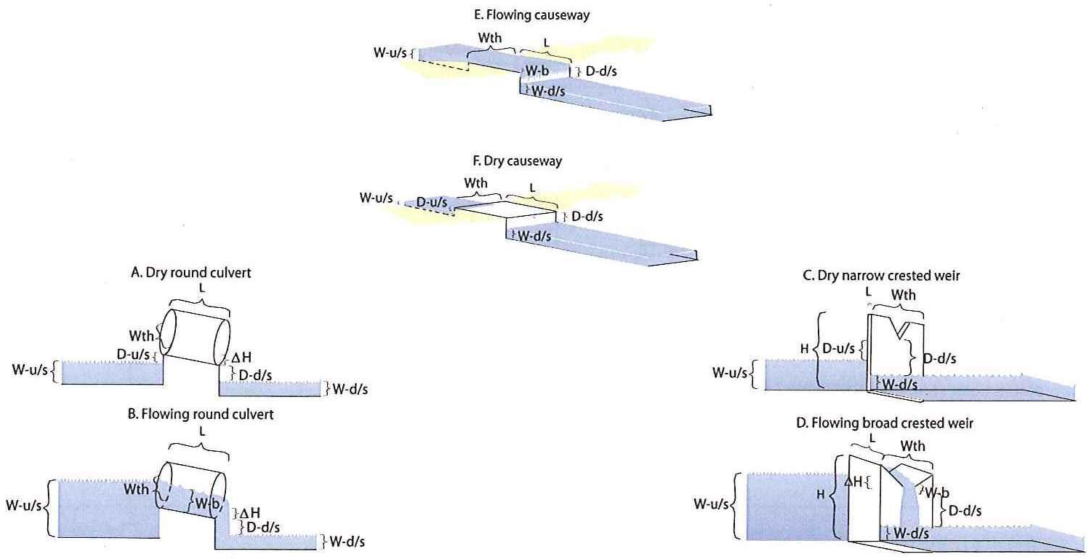
SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
BARRIER ASSESSMENT - 100m sampling site

NATURAL AND ARTIFICIAL BARRIERS IN 100m SITE

No barriers ☐

Description		Barrier 1	Barrier 2	Barrier 3
	Type of Barrier – artificial (see bottom of page for types) or natural			
	Longitude or Northing			
	Latitude or Easting			
	Tick when photo taken			
L	Length (longitudinal) (m)			
ΔH	Height difference across barrier (m)			
Wth	Width or diameter (cross-section) (m)			
H	Height (m)			
W – b	Water depth across barrier (m)			
D – d/s	Downstream drop (bottom of barrier to water) (m)			
W – d/s	Water depth – downstream (m)			
D – u/s	Upstream drop (bottom of barrier to water) (m)			
W – u/s	Water depth – upstream (m)			
	Blockage – overgrowth or sedimentation % cross-sectional area			
	Flow over barrier (either measure or describe)			
	Structure material (e.g. concrete, timber, steel, plastic, loose rock)			
	If culvert, number or pipes or boxes			
	Barrier floods at flow condition (extremely high, high, medium, low flows)			

Note: Not all of the above measurements will apply to natural barriers.



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SW-WA RIVER HEALTH ASSESSMENT – FIELD SHEETS
100m sampling site

NATURAL OR ARTIFICIAL BARRIERS OUTSIDE 100m SITE

Artificial barriers outside 100m site (upstream or downstream)		Circle
Unknown	None	Yes (see below)
Description and distance from site (if time, assess as per previous page).		

Natural barriers outside 100m site (upstream or downstream)		Circle
Unknown	None	Yes (see below)
Description and distance from site (if time, assess as per previous page).		

CHANNELISATION

Signs of channelisation	No ☐	Yes ☐ (describe below)

Note whether channelisation is due:

1. **Direct causes**: deepening and straightening by humans to increase water flow (e.g. to reduce flooding), or
2. **Indirect causes:** deepened systems with more vertical banks due to bank erosion and bed scouring; a result of increased flows from changes such as catchment clearing or hydrological modifications.

WATER VELOCITY (FLOW) ACROSS 100m SAMPLE SITE

Flow information is recorded on the Macroinvertebrate Sampling Sheet and WQ 2 Sheet, if neither is being used for this assessment use space provided below.

Meter or Method used ________________ units ________ Velocity____________

WEATHER CONDITIONS

Rain in past week	Tick box
Yes	
No	
If known, mm	

Cloud cover	%
Day 1	
Day 2	

Rain	Tick box
Day 1	Yes ☐ No ☐
Day 2	Yes ☐ No ☐

Weather comments ________________________________

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
WATER QUALITY 1: GRAB AND IN-SITU SAMPLES

Recorders name ______________________

PRE - INSTRUMENT CALIBRATION

Instrument Type ______________________ Instrument Number ______________________

Pre – field calibration	Electrical Conductivity (mS/cm)	pH 7	pH 10	Dissolved Oxygen (% sat)	Salinity	Temperature
Pre reading						
Post reading						

NOTE: In most cases salinity and temperature are not calibrated prior to use.

Circle:

Conductivity units	uncomp	comp (25°C)	
Conductivity setting	fresh	salt	none
Salinity setting	2311	Other (indicate):	
Electrical conductivity calibration solution used	1.413 mS/cm	Other (indicate):	
Dissolves oxygen calibrated to	100% sat. in air	Other (indicate):	

Barometric pressure from BOM (if required) for DO calibration

Full state: 1900 955 366
Coastal: 1900 969 902

________ hPa ______ mmHg
(mmHg = hPa x 0.7502)

GRAB WATER QUALITY

Water quality samples taken

Date ______________ Time ______________

Sample number ______________ COC ______________

IN-SUTU WATER QUALITY

	Date	Time (24 hrs)	Salinity (ppt)	pH	Dissolved oxygen (mg/L)	Dissolved Oxygen (% sat)	Electrical Conductivity (mS/cm)	Temperature (°C)	Add any others here	
Surface										
Bottom										

Note: Usually only surface water samples are taken.

POST - INSTRUMENT CALIBRATION

Post – field calibration	Electrical Conductivity (mS/cm)	pH 7	pH 10	Dissolved Oxygen (% sat)	Salinity	Temperature (°C)
Pre reading						
Post reading						

NOTE: In most cases pH 10 does not require post calibration. Dissolved oxygen is only checked, not post calibrated

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SW-WA FARWH – FIELD SHEETS
WATER QUALITY 2: DIEL DISSOLVED OXYGEN AND TEMPERATURE

Recorders name ____________________________

PRE-DEPLOYMENT MEASUREMENTS

Deployment date _______________ Deployment time _______________

Probe Letter	Pump Number	Field air calibration			Water readings (mg/L)	Pump running (yes or no)	Water depth to first inlet hole (cm)	Actual water depth (m)
		Pre-cal (mg/L)	Span (%)	Post-cal (mg/L)				

LOCATION OF LOGGERS

Circle one each category (except for in-stream vegetation)

Location in stream	In main flow	Off main flow	Other (describe)	
Angle loggers deployed	90° (vertical)	45 to 90°	< 45°	
Canopy cover over loggers	0%	10 to 50%	50% to 80%	100%
In-stream vegetation* (tick all applicable)	None	Emergent	Submerged	Floating
Density of in-stream, vegetation*	N/A	Sparse	Medium	Dense
Density of algae in water column*	None	Sparse	Medium	Dense
Riffles/cascades (upstream of loggers)**	None		If yes ____________ m upstream	

* within 1m from loggers. ** within 50m from loggers

Notes ____

WATER VELOCITY (FLOW) AT LOGGER SITE

Meter or Method used ____________________ units ________ Velocity___________

POST DEPLOYMENT MEASUREMENTS

Retrieval date ___________ Retrieval time ___________

Probe Letter	Pump running	Condition of HOUSING	Condition of MEMBRANE		Water reading (mg/L)	Air reading (mg/L)
	No Slow Fast	Clean Slightly dirty Very dirty	Clean Slightly dirty Very dirty	Bubbles No bubbles		
	No Slow Fast	Clean Slightly dirty Very dirty	Clean Slightly dirty Very dirty	Bubbles No bubbles		

Weather observations in past 24 hours and/or any noticeable changes to site or loggers ______________________
____
____

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SW-WA FARWH – FIELD SHEETS
WATER QUALITY 3: MULTI PARAMETER LOGGING

Recorders name ____________________________

PRE-DEPLOYMENT INSTRUMENT CALIBRATION

Instrument Type ______________________ Logger Number _______________ Handpiece Number _______________

Pre – field Calibration	Salinity	pH 7	pH 10	Dissolved Oxygen (% sat)	Electrical Conductivity (mS/cm)	Temperature (°C)
Reading						
Calibrated to						

NOTE: In most cases salinity and temperature are not calibrated prior to use.

Barometric pressure from BOM (if required) for DO calibration

Full state: 1900 955 366
Coastal: 1900 969 902

________ hPa ______ mmHg
(mmHg = hPa x 0.7502)

LOGGING INFORMATION

Deployment date ________________ Deployment time ________________

Parameters set to log (tick)
[ ] Dissolved Oxygen [ ] Temperature [ ] Electrical conductivity
[ ] pH [ ] Turbidity [ ] Other ________________

Loggers set to record every ___________________ mins for __________________ days / hours (circle)

LOCATION OF LOGGERS

Circle one option for each category (except for in-stream vegetation)

Location in stream	In main flow	Off main flow	Other (describe)	
Angle loggers deployed	90° (vertical)	45 to 90°	< 45°	
Canopy cover over loggers	0%	10 to 50%	50% to 80%	100%
In-stream vegetation* (tick all applicable)	None	Emergent	Submerged	Floating
Density of in-stream, vegetation*	N/A	Sparse	Medium	Dense
Density of algae in water column*	None	Sparse	Medium	Dense
Riffles/cascades (upstream of loggers)**	None		If yes ______________ m upstream	

* within 1m from loggers. ** within 50m from loggers

Notes ____

WATER VELOCITY (FLOW) AT LOGGER SITE

Meter or Method used ______________________ units ________ Velocity _____________

LOGGER REMOVAL

Logger removal date ___________ Logger removal time ___________

Weather observations in past 24 hours and/or any noticeable changes to site or loggers ______________________________
____

Post – field Calibration	Salinity	pH 7	pH 10	DO%	Electrical Conductivity (mS/cm)	Temperature (°C)
Reading						
Calibrated to						

NOTE: In most cases pH 10 does not require post calibration. Dissolved oxygen is only checked, not post calibrated

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
FISH AND CRAYFISH

Recorders name ________________________ Date traps deployed ________________________

☐ (tick) Local Fisheries WA officer called (1800 815 507) up to one day prior (need permit number, car registration and samplers names)

TRAP SETTING – BOX TRAPS

Trap #	Small trap (S) or Large trap (L)	Left bank (LB) Right bank (RB) or Centre (C)	Water Depth (cm)	Describe location of trap e.g. in woody debris, under log, amongst emergent macrophytes, in full sun, % shaded, under overhanging vegetation, amongst tree roots.

TRAP SETTING – FYKE NETS

TYPE		Water Depth (cm)	% stream width *	Comments e.g. fyke in eddy, gaps between wings and bank or river bottom
Dome (D) or Rectangle (R)	Upstream (US) or Downstream DS)			

*If both wings are fully extended to edge of bank this would be 100%. If spaces exist between wings and bank or between wings and surface of water (due to depth), estimate coverage and provide explanation of set-up.

LIST FISH/CRAYFISH SPECIES OBSERVED BUT NOT CAUGHT

____

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Date ________________ Site code ________________

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
FISH AND CRAYFISH

Recorders name ________________________ Date traps collected ________________________

TRAP COLLECTION

Trap #		Size class (mm)					Evidence of Reproduction*	Comments (for example) • staining, parasites, disease, injury • smallest size gravid individual • size of largest individual ***Note size of marron over 76mm***
	Fish	0-20	20 - 50	50 - 100	100 +	Other	none	
	Crayfish	0-20	20 - 50	50 - 76	76 - 100	100+	✓ (few)	
	Large fish	0-100	100-200	200-400	400+	Other	✓✓ (many)	

**Evidence of reproductive condition includes gravid females &/or characteristic colours*

Legend
WM = Western Minnow, **TM** = Trout Minnow, **BSM** = Black-stripe Minnow, **NF** = Nightfish, **WPP** = Western Pygmy Perch, **BPP** = Balstons Pygmy Perch, **SWG** = South West Goby, **SRG** = Swan River Goby, **COB** = Cobbler, **JOL** = Jollytail, **GAM** = Gambusia, **1SPOT** = One spot live bearer, **WH** = Western Hardy Head, **ELONG** = Elongata, **BB** = Black Bream, **RP** = Redfin Perch, **RT** = Rainbow Trout, **BT** = Brown Trout, **MM** = Mud Minnow, **GIL** = Gilgie, **GH** = Hybrid Gilgie, **MAR** = Marron, **HMAR** = Hairy Marron, **K** = Koonac, **KX** = Koonac sp X, **Y** = Yabbie, **FS** = Freshwater Shrimp.

Large fish include: cobbler, trout, redfin, lamprey.

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Department of Water

SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
MACROINVERTEBRATES: AUSRIVAS FIELD SHEET

Recorders name ________________________

DATE SAMPLE TAKEN ________________________ TIME SAMPLE TAKEN ________________________

COLLECTED BY ________________________ PICKED BY ________________ AND ________________

HABITAT ________________________ % OF 100 m reach ________________________

SAMPLE NUMBER ________________________ COC NUMBER ________________________

SAMPLING CONDITIONS [ ] good [ ] average [ ] poor

PICKING CONDITIONS [ ] good [ ] average [ ] poor

BREAKDOWN OF 10m SAMPLING AREA

Mineral Substrate	%	**Habitat surface area**	%	*Density (circle) (1= sparse, 5 = dense)*
Bedrock		Mineral substrate		
Boulders (>256mm or scorer ball)		Emergent macrophyte		1 2 3 4 5
Cobble (64 to 256mm or cricket to soccer ball		Submerged macrophyte		1 2 3 4 5
Pebble (16 to 64mm or 5c piece to cricket ball)		Floating macrophyte		1 2 3 4 5
Gravel (4 to 16mm or raw sugar to 5c piece)		Detritus		1 2 3 4 5
Sand (1 to 4mm)		Algal Cover		1 2 3 4 5
Silt (<1mm)		Riparian veg draped in water		
Clay		Other (e.g. woody debris)		
Total	100%	Total (may be > 100%)		

DEPTH

Depth macroinvertebrate sample taken (circle) <25cm <50cm <100cm < 200cm > 200cm

WATER VELOCITY (FLOW) AT MACROINVERTEBRATE SITE

Meter or Method used ________________ units ________ Max velocity ____________ Min velocity____________

BOX SUB-SAMPLER TALLY

Number of cells picked ____________

Number of cells in box ____________

Total number of macroinvertebrates picked ____________

Comments (if any)

____

____

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Appendix E — Chemistry and particle size analysis

Parameter	Description	Analysis method	Limit of reporting (mg/kg dry sediment)
Particle size analysis	Determination of the particle size distribution of sediment. Particles grouped into the following size classes according to the Wentworth scale (Wentworth 1922): <4 µm (clay) <62 µm (silt) <250 µm (fine sand) <500 µm (medium sand) <2000 µm (coarse sand) <10 000 µm (gravel).	Wet sieving followed by laser diffraction (Mudroch et al. 1997).	n/a
Moisture content	Determination of the percentage of water present in the sediment sample.	Gravimetric measurement of weight loss	n/a
Total organic carbon (TOC)	Measurement of TOC within the sediments, required for normalisation of organic compound data to 1% organic carbon in accordance with guidelines (ANZECC and ARMCANZ 2000). *Units: mg/kg dry sediment.*	ANZECC and ARMCANZ 2000	100
Bioavailable metals*	Measurement of bioavailable metals suite: Aluminium Arsenic Cadmium Chromium Copper Iron Lead Mercury Silver Zinc *Units: mg/kg dry sediment.*	Analysis of dried sediment sample for a range of metals using a cold dilute acid extraction (0.5–1.0 M hydrochloric acid in sediment to acid ratio of 1:50 for one hour – according to ANZECC and ARMCANZ 2000).	0.2 mg/kg for mercury; 1.0 mg/kg for iron, 0.5 mg/kg for other metals
Organochlorine (OC) pesticides	Measurement of OC pesticide suite: HCB Heptachlor Heptachlor epoxide Aldrin gamma-BHC (Lindane)	GC-MS, GC-ECD analysis (APHA 1998).	0.001 mg/kg

Parameter	Description	Analysis method	Limit of reporting (mg/kg dry sediment)
	alpha-BHC beta-BHC delta-BHC trans-Chlordane cis-Chlordane Oxychlordane Dieldrin p,p’-DDE p,p’-DDD p,p’-DDT Endrin Endrin Aldehyde Endrin Ketone alpha endosulphan beta endosulphan Endosulphan sulphate Methoxychlor *Units: mg/kg dry sediment.*		
Organophosphate (OP) pesticides	Dichlorvos Demeton-S-Methyl Diazinon Dimethoate Chlorpyrifos Chlorpyrifos Methyl Malathion (Maldison) Fenthion Ethion Fenitrothion Chlorfenvinphos € Chlorfenvinphos (Z) Parathion (Ethyl) Parathion Methyl Pirimiphos Ethyl Pirimiphos Methyl Azinphos Methyl Azinphos Ethyl *Units: mg/kg dry sediment.*	Extract using Hexane/acetone. Cleanup using GPC if required then concentrate extract. LV-GC/MS	0.01 mg/kg
Phenoxy Acid Herbicide Suite	Dicamba MCPA Dichlorprop 2,4-D 2,4,5-T	GC-MS, GC-ECD analysis (USEPA 8080/8140 1996e; APHA 1998)	1 ug/L

Parameter	Description	Analysis method	Limit of reporting (mg/kg dry sediment)
	2,4,5-TP 2,4-DB MCPP Triclopyr Picloram Clopyralid Fluroxypyr		
Non-organochlorine and non-organophosphate herbicides	Atrazine Diuron Hexazinone Linuron Metolachlor Molinate Oxyfluorfen Pendimethalin Prometryn Simazine Trifluralin *Units: ug/L*		0.1 ug/L

**Bioavailable metals are extracted from sediment using a cold dilute acid extraction. This is designed to extract only metals loosely bound to the surface of sediment particles, rather than those tightly bound in the mineral matrix (ANZECC and ARMCANZ 2000). This is considered to provide an approximation of the metals that are biologically available.*

Appendix F — Size categories for fish

Small finfish (Total length, mm)	**Large finfish (Total length, mm)**	**Crayfish (Carapace length, mm)**
0–20*	0–100*	0–20*
20–50	100–200	20–50
50–100	200–400	50–76
+100	+400	76–100
Species include:	***Species include:***	***Species include:***
Western pygmy perch	Freshwater cobbler	Gilgie species
Western minnow	Lamprey	Marron species
Nightfish		Koonac species
Swan River goby	*Also includes the western long-necked tortoise*	Yabby species
Western hardyhead		
South-western goby		
Mosquitofish		
One-spot livebearer		
Mud minnow		

** Size ranges have been calibrated to each species where the lowest size range generally relates to a juvenile/young-of-year of that species*

Appendix G — Expected fish and crayfish species list

Table G1 Expected native species, by site

River	Site	***Sub-catchment ID (DoW)***	***Native fish – freshwater***					***Native fish – freshwater with marine affinities***				***Native crayfish – freshwater***				References
			G. occidentalis	*G. munda*	*N. vittata*	*B. porosa*	*T. bostocki*	*P. olorum*	*A. suppositus*	*L. wallacei*	*G. australis*	*C. cainii*	*C. quinque-carinatus*	*C. crassimanus*	*C. preissi*	
McLeod Creek	MRAP1	1814	✓	✓	✓	✓		✓				✓	✓	✓		Beatty et al. (2008) – four sites in lower catchment (within 5 km of confluence with Blackwood River), sampled December 2007.
	MRAP2		✓	✓	✓	✓		✓				✓	✓	✓		
	MC02		✓	✓	✓	✓		✓				✓	✓	✓		
	MRAP8		✓	✓	✓	✓		✓				✓	✓	✓		
	MCLEOD	3539	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		White et al. (2013) (this study)
	MC10	2334	✓		✓	✓	i	✓	✓	✓		✓	✓	✓		
Rushy Creek	RRAP9	1496	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		Beatty et al. (2008) – two sites in lower catchment (within 2 km of confluence with McLeod Creek), sampled December 2007.
	RRAP6		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		
	RRAP10		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		
	RUSHYCK		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		Beatty et al. (2012) – eight sites in lower catchment (within 2 km of confluence with McLeod Creek), sampled August to October 2010 and 2011. White et al. 2013 (this study)
Chapman Brook	CHAP12	1417	✓									✓	✓			White et al. 2013 (this study).
	CHAPX1	2323	✓		✓	✓					i	✓	✓	✓		Morrissy (1978) (*C. cainii* distribution) [1]

			Native fish – freshwater					***Native fish – freshwater with marine affinities***				***Native crayfish – freshwater***				
River	**Site**	***Sub-catchment ID (DoW)***	*G. occidentalis*	*G. munda*	*N. vittata*	*B. porosa*	*T. bostocki*	*P. olorum*	*A. suppositus*	*L. wallacei*	*G. australis*	*C. cainii*	*C. quinque-carinatus*	*C. crassimanus*	*C. preissi*	**References**
Upper Chapman Brook	UCHAP1	1401	✓	✓	✓	✓					✓	✓	✓	✓		White et al. 2013 (this study) [2]
	UCHAPX2		✓	✓	✓	✓					✓	✓	✓	✓		
	UCHAP5		✓	✓	✓	✓					✓	✓	✓	✓		
	UCHAP6		✓	✓	✓	✓					✓	✓	✓	✓		
Fisher Creek	FISHX3	3549		✓								#	✓	✓	✓	White et al. 2013 (this study)

✓ species found in the subcatchment (DoW Hydrographic subcatchments) by one or more studies.

i species is likely to be present based on interpolation of recorded presence in subcatchments upstream of downstream.

 # Fisher Creek is included in distribution of C. cainii by Morrissy (1978), however this species is unlikely to be found at this site as the stream flows intermittently.

[1] *WRM (2008a) found* N. vittata, G occidentalis, B. Porosa, P. olorum *and* G. australis *in Chapman Brook however results were reported for the Brook as a whole, not by site, hence they could not be attributed to each subcatchment.*

[2] *Lower Blackwood LCDC (2004) reports anecdotal evidence of* G. australis *observed in the Upper Chapman Brook.*

Table G2 Exotic species by tributary system

River	*G. holbrooki*	*P. caudimaculatus*	*C. auratus*	*Cherax* spp. (yabby)	References
McLeod Creek	✓	✓		✓	Beatty et al. (2008) – four sites in lower catchment (within 5 km of confluence with Blackwood River), sampled December 2007. White et al. (2013) (this study)
Rushy Creek	✓		✓	✓	Beatty et al. (2008) – two sites in lower catchment (within 2 km of confluence with McLeod Creek), sampled December 2007. White et al. (2013) (this study)
Chapman Brook	✓				Morgan et al. (1998) – one site midway between Blackwood River and confluence with Upper Chapman; sampled once between 1994 and 1996 White et al. 2013 (this study)
Upper Chapman Brook	✓			✓	Morgan et al. (1998) – one site in lower catchment, sampled once between 1994 and 1996. White et al. 2013 (this study)
Fisher Creek					White et al. 2013 (this study)

Appendix H — SWIRC index and sub-index scores

Index Sub-index *Component*	MRAP1	MRAP2	MC02	MRAP8	MCLEOD	MC10	RRAP9	RRAP6	RRAP10	RUSHYCK	CHAP12	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3	BLA15/16
Aquatic biota index	0.66	0.81	0.55	0.75	0.90	0.54	0.59	0.81	0.54	0.67	0.68	0.74	0.18	0.64	0.78	0.81	1.00	
Fish and crayfish	0.68	0.81	0.57	0.85	0.89	0.92	0.73	0.76	0.83	0.82	0.84	0.95		0.92	0.95	0.94	1.00	
Expectedness	0.36	0.62	0.51	0.69	0.87	0.84	0.54	0.53	0.66	0.79	0.67	0.98		0.92	0.90	0.95	1.00	
Nativeness	1.00	1.00	0.64	1.00	0.91	1.00	0.91	1.00	1.00	0.86	1.00	0.92		0.92	1.00	0.92	1.00	
Macro-invertebrate	0.63	0.82	0.52	0.66	0.91	0.16	0.45	0.86	0.26	0.52	0.53	0.53	0.18	0.35	0.61	0.68	0.69	
Water quality index	0.71	0.95	0.95	0.80	0.90	0.90	0.80	0.90	0.70	0.80	0.80	0.86		0.95	0.90	0.95	0.85	1.00
Diel dissolved oxygen	0.71	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.84	0.86		1.00	1.00	1.00	1.00	
Salinity	1.00	1.00	1.00		1.00	1.00			1.00	1.00	1.00	1.00			1.00	1.00	1.00	
WQ – non-critical sub-indices	0.80	0.95	0.95	0.80	0.90	0.90	0.80	0.90	0.70	0.80	0.80	0.95		0.95	0.90	0.95	0.85	1.00
Diel temperature	0.40	0.80	0.80	0.40	0.80	0.80	0.40	0.80	0.80	0.40	0.40	0.80		0.80	0.80	0.80	0.40	
Total nitrogen	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	1.00	1.00		1.00	0.80	1.00	1.00	1.00
Total phosphorus	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00
Turbidity	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80	0.40	1.00	0.80	1.00		1.00	1.00	1.00	1.00	1.00
Fringing zone index	0.43	0.76	0.92	0.76	0.84	0.89	0.58	0.55	0.63	0.35	0.59	0.73	0.97	0.48	0.45	0.61	1.00	0.84
Nativeness	0.60	0.80	0.85	0.80	0.90	1.00	0.50	0.60	0.95	0.55	0.70	1.00	0.95	0.45	0.60	0.58	1.00	1.00
Ground cover layer	0.20	0.80	0.80	0.60	0.80	1.00	0.10	0.40	0.90	0.10	0.80	1.00	0.90	0.10	0.20	0.15	1.00	1.00
Shrub layer	1.00	0.80	0.90	1.00	1.00	1.00	0.90	0.80	1.00	1.00	0.60	1.00	1.00	0.80	1.00	1.00	1.00	1.00
Extent	0.26	0.72	0.98	0.73	0.79	0.78	0.66	0.50	0.30	0.15	0.48	0.47	1.00	0.51	0.29	0.65	0.99	0.69
Width	0.23	0.69	0.98	0.67	0.71	0.71	0.59	0.41	0.28	0.12	0.45	0.43	1.00	0.40	0.25	0.57	0.99	0.65
Length	0.29	0.76	0.98	0.78	0.87	0.84	0.72	0.59	0.32	0.17	0.50	0.51	1.00	0.62	0.34	0.74	1.00	0.73
Physical form index	0.88	0.79	0.87	0.66	0.83	0.68	0.68	0.47	0.65	0.52	0.71	0.67	0.76	0.49	0.56	0.70	0.93	0.79
Artificial channel	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Erosion	0.83	0.83	0.77	0.54	0.71	0.50	0.58	0.15	0.50	0.21	0.81	0.79	0.79	0.27	0.38	0.81	0.88	0.79
Erosion extent	1.00	1.00	1.00	0.67	1.00	0.67	1.00	0.00	0.33	0.00	1.00	1.00	1.00	0.00	0.00	1.00	1.00	1.00
Bank stabilisation	0.67	0.67	0.54	0.42	0.42	0.33	0.17	0.29	0.67	0.42	0.63	0.58	0.58	0.54	0.75	0.63	0.75	0.58
Longitudinal connectivity	0.95	0.67	0.97	0.64	0.97	0.77	0.64	0.67	0.67	0.74	0.54	0.46	0.64	0.51	0.56	0.51	0.97	0.69
Major dams	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Minor dams	1.00	0.00	1.00	0.00	1.00	0.25	0.00	0.00	0.00	0.25	0.00	0.00	0.25	0.00	0.00	0.00	1.00	0.50
Gauging stations	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	0.00	0.50	0.25	0.50	0.25	1.00	0.25
Rail-road crossings	0.50	0.75	0.75	0.50	0.75	1.00	0.50	0.75	0.75	0.75	0.50	0.75	0.75	0.75	0.75	0.75	0.75	1.00

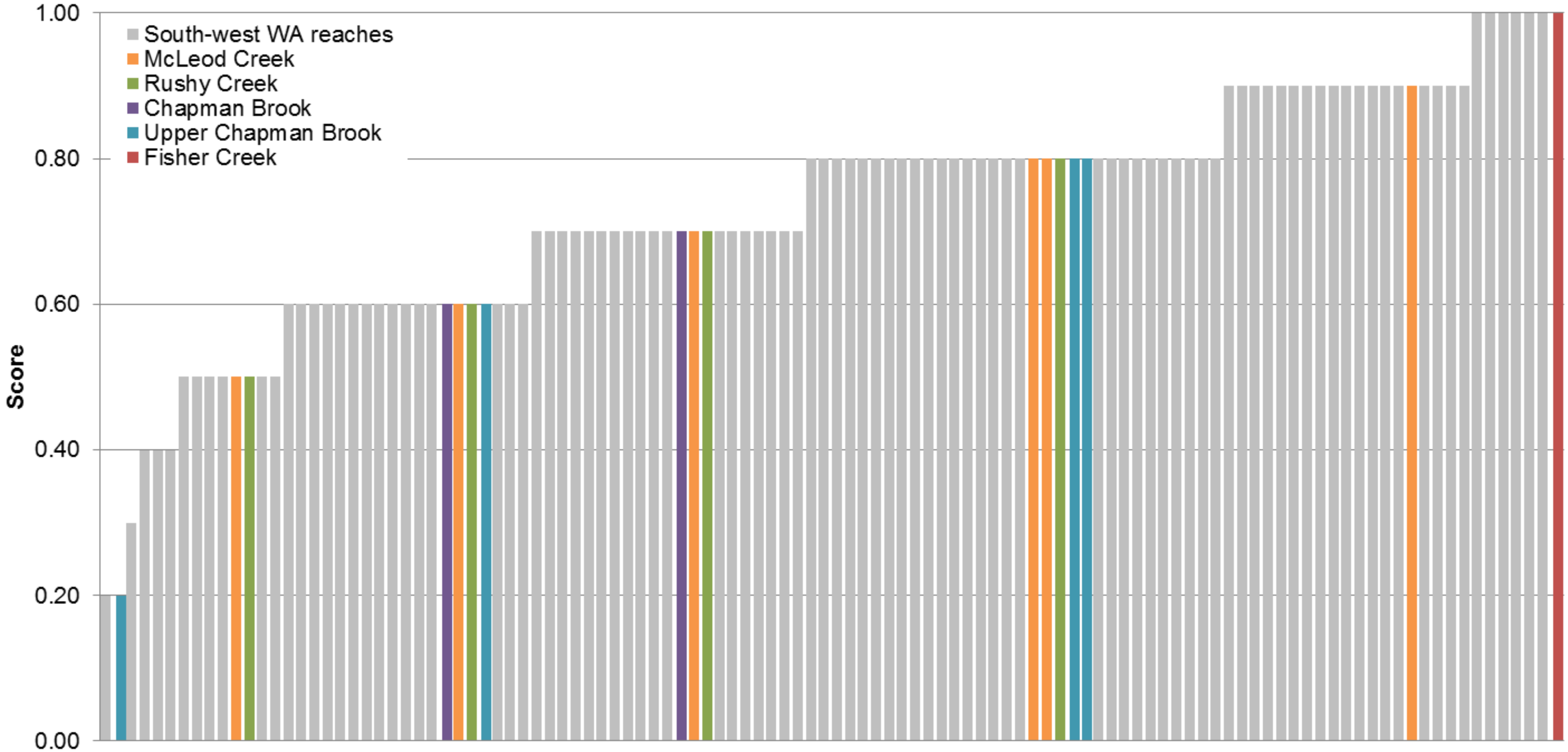
Index Sub-index *Component*	**MRAP1**	**MRAP2**	**MC02**	**MRAP8**	**MCLEOD**	**MC10**	**RRAP9**	**RRAP6**	**RRAP10**	**RUSHYCK**	**CHAP12**	**CHAPX1**	**UCHAP1**	**UCHAPX2**	**UCHAP5**	**UCHAP6**	**FISHX3**	**BLA15/16**
Catchment disturbance index	0.70	0.80	0.97	0.77	0.81	0.71	0.71	0.67	0.75	0.67	0.72	0.79	0.98	0.78	0.91	0.80	0.99	0.80
Land use	0.70	0.81	0.97	0.85	0.82	0.71	0.71	0.67	0.75	0.67	0.73	0.79	0.98	0.78	0.91	0.80	0.99	0.80
Infrastructure	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Land cover change	1.00	0.99	1.00	0.92	0.99	1.00	1.00	1.00	1.00	1.00	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00
Hydrological change index											0.7							
Flow stress ranking											0.7							
Low flow											1.0							
High flow											0.3							
Proportion of zero flow											0.8							
Monthly variation											0.9							
Seasonal period											0.7							

Note: SWIRC scoring categories and condition bands (Storer et al. 2011a)

SWIRC score category	**Condition band**
0.8 – 1.0	Largely unmodified
0.6–0.79	Slightly modified
0.4 – 0.59	Moderately modified
0.2 – 0.39	Substantially modified
0 – 0.19	Severely modified

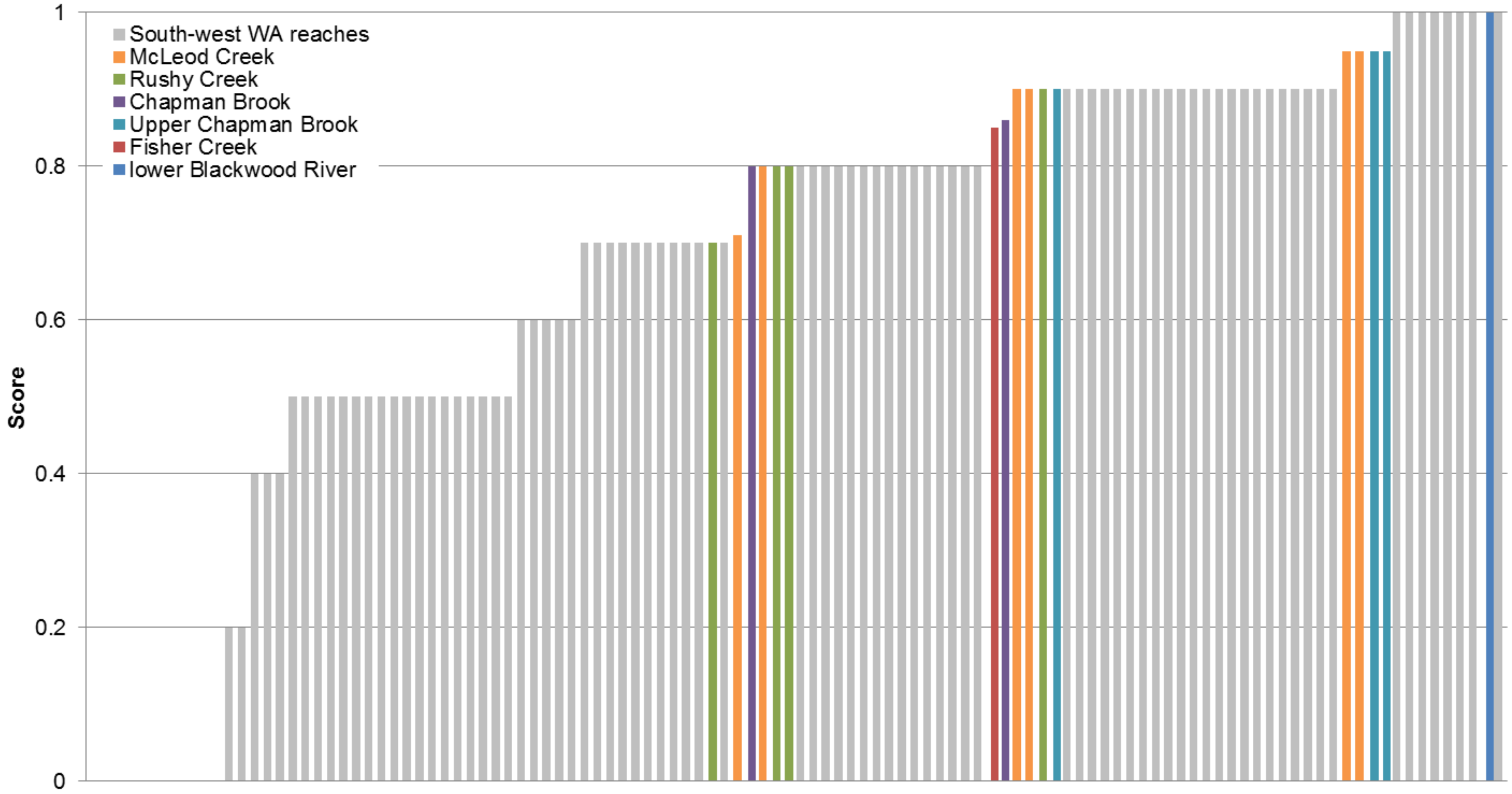
Appendix I — SWIRC index scores for south-west Western Australia

Figure I1 Aquatic biota index



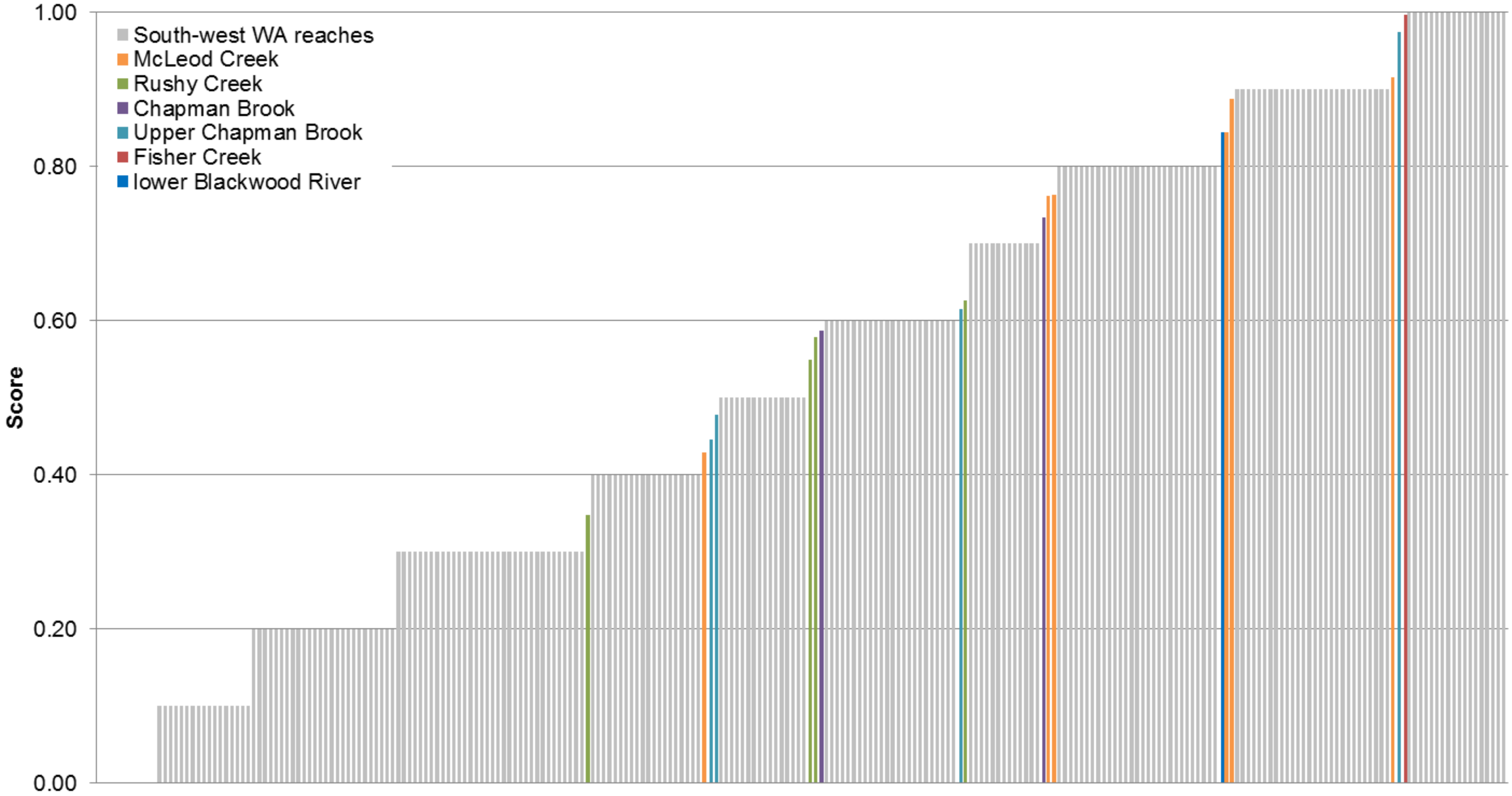
Note: the scores for the 2008 and 2009 assessment were rounded to one decimal place as required for reporting under the FARWH, whereas those for this study are rounded to one decimal place. For the reach and site definition for the 2008 and 2009 assessment, see Storer et al. 2011b.

Figure I2 Water quality index



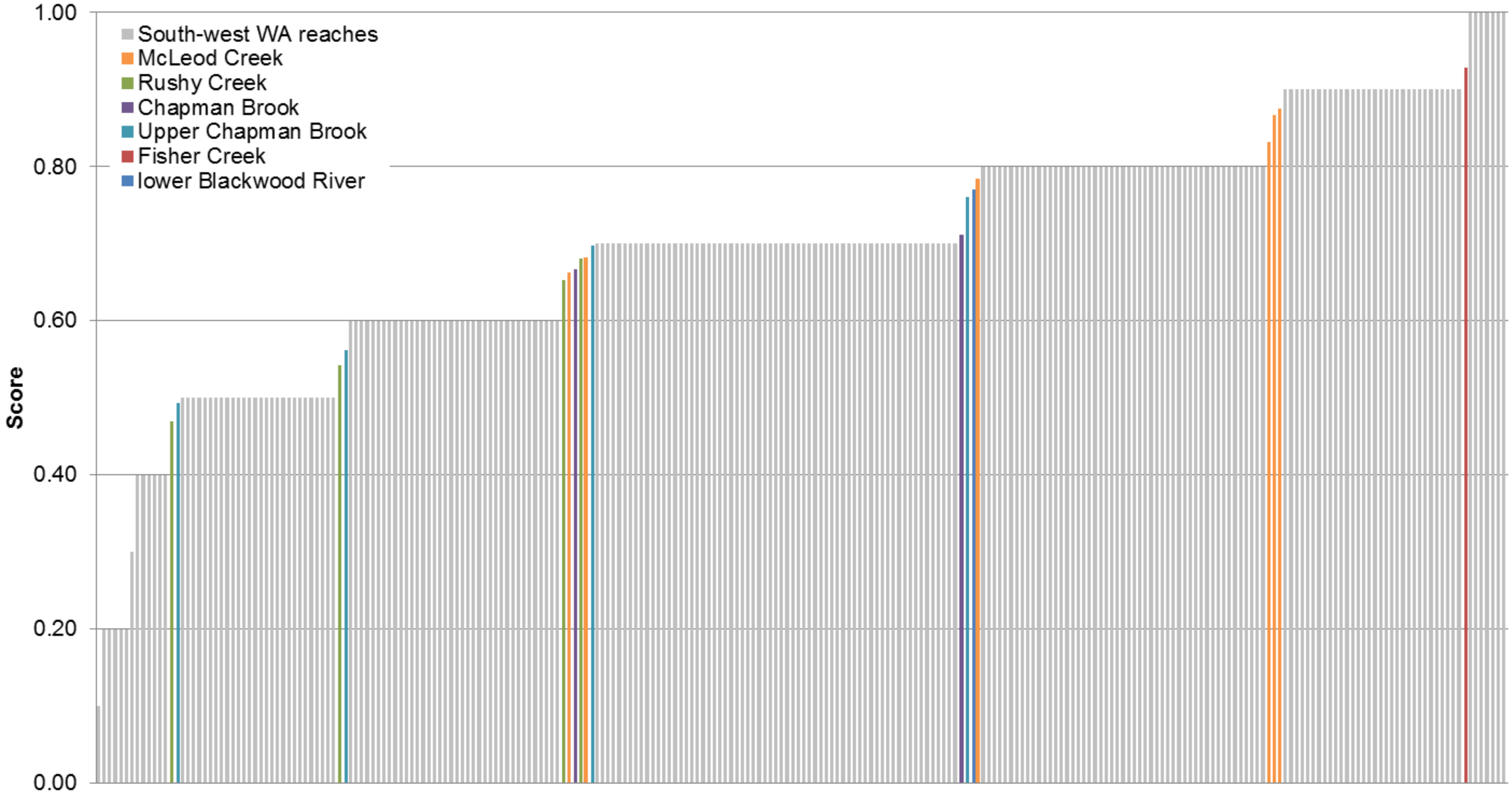
Note: the scores for the 2008 and 2009 assessment were rounded to one decimal place as required for reporting under the FARWH, whereas those for this study are rounded to one decimal place. For the reach and site definition for the 2008 and 2009 assessment, see Storer et al. 2011b.

Figure I3 Fringing zone index



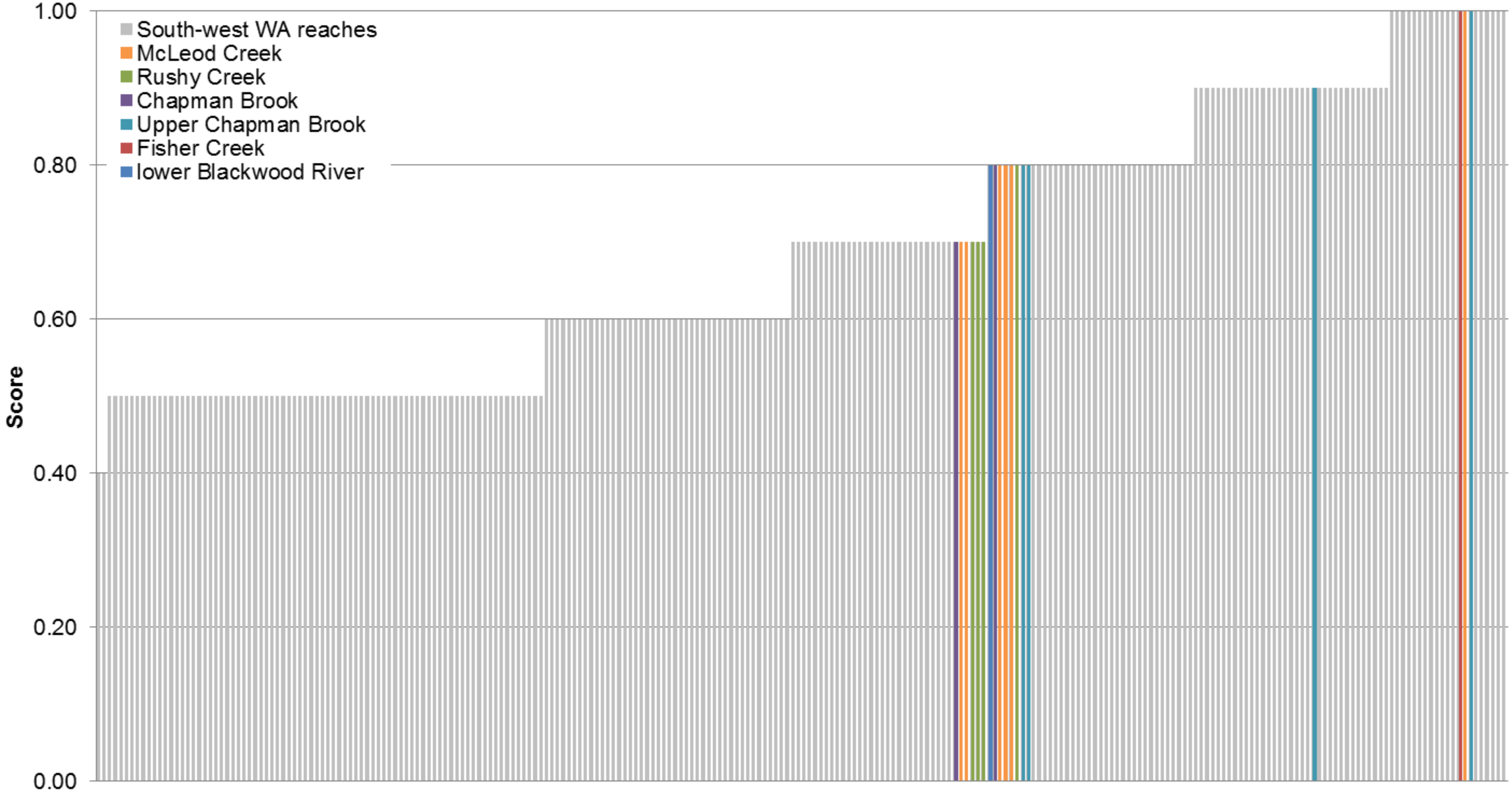
Note: the scores for the 2008 and 2009 assessment were rounded to one decimal place as required for reporting under the FARWH, whereas those for this study are rounded to two decimal places. For the reach and site definition for the 2008 and 2009 assessment, see Storer et al. 2011b.

Figure I4 Physical form index



Note: the scores for the 2008 and 2009 assessment were rounded to one decimal place as required for reporting under the FARWH, whereas those for this study are rounded to two decimal places. For the reach and site definition for the 2008 and 2009 assessment, see Storer et al. 2011b.

Figure I5 Catchment disturbance index



Note: the scores for the 2008 and 2009 assessment were rounded to one decimal place as required for reporting under the FARWH, whereas those for this study are rounded to two decimal places. For the reach and site definition for the 2008 and 2009 assessment, see Storer et al. 2011b.

Appendix J — Infrastructure sub-theme

Reach code	Area covered by infrastructure (km^2)	Reach catchment area (km^2)	Area of infrastructure as % of reach catchment area	Infrastructure sub-index score
MRAP1	0.050	3.10	1.61	0.99
MRAP2	0.205	15.26	1.34	0.99
MC02	0.474	35.62	1.33	0.99
MRAP8	0.061	6.49	0.94	0.99
MCLEOD	0.219	27.98	0.78	1.00
MC10	0.011	3.65	0.30	1.00
RRAP9	0.045	2.74	1.64	0.99
RRAP6	0.085	10.44	0.81	1.00
RRAP10	0.070	7.09	0.98	0.99
RUSHYCK	0.006	2.13	0.30	1.00
CHAP12	0.104	7.84	1.33	0.99
CHAPX1	0.619	57.13	1.08	0.99
UCHAP1	0.027	3.14	0.87	1.00
UCHAPX2	0.310	35.73	0.87	1.00
UCHAP5	0.340	36.03	0.94	1.00
UCHAP6	0.217	19.11	1.13	0.99
FISHX3	0.220	33.84	0.65	1.00
BLA15/16	0.372	48.56	0.77	1.00

Appendix K — Artificial channel sub-theme

Reach code	Length of reach (km)	Length of reach mapped as canal line*	% of reach length classified as artificial channel	Artificial channel sub-index score
MRAP1	2.50	0	0	1.0
MRAP2	2.50	0	0	1.0
MC02	4.50	0	0	1.0
MRAP8	4.16	0	0	1.0
MCLEOD	7.00	0	0	1.0
MC10	1.45	0	0	1.0
RRAP9	3.09	0	0	1.0
RRAP6	6.01	0	0	1.0
RRAP10	3.96	0	0	1.0
RUSHYCK	2.00	0	0	1.0
CHAP12	3.70	0	0	1.0
CHAPX1	12.22	0	0	1.0
UCHAP1	2.30	0	0	1.0
UCHAPX2	4.57	0	0	1.0
UCHAP5	7.37	0	0	1.0
UCHAP6	5.27	0	0	1.0
FISHX3	13.19	0	0	1.0
BLA15/16	12.40	0	0	1.0

** Mapped as canal line in Hydrography theme of GEODATA TOPO 250K Series 3*

Appendix L — Water quality data (2012–13)

River	Site code	Date	Time	Alkalinity as CaCO3 (mg/L)	DOC (mg/L)	Colour (TCU)	Cond comp to 25°C [in situ] (mS/cm)	D Org N (mg/L)	N0x [NO_2+NO_3] (mg/L)	TKN (mg/L)	TN (mg/L)	N as NH_3/NH_4 (mg/L)	DO %	DO [in situ] (mg/L)	TP (mg/L)	pH	SRP (mg/L)	Salinity (mg/L)	Temperature [in situ] (°C)	TSS (mg/L)	Turbidity (NTU)	Flow status	Sample comment
McLeod Creek	MRAP1	9/10/2012	9:15:00	29	5	58		0.46	0.12	0.57	0.69	0.017			0.021		<0.005			1	3.3	Flow – flowing	
	MRAP2	9/10/2012	15:35:00	22	2	18		0.2	0.25	0.2	0.45	<0.01			<0.005		<0.005			<1	1.2	Flow – flowing	
	MC02	18/06/2012	12:34:00		5	23	0.531	0.15	2	0.16	2.1	<0.01	79.7	8.27	<0.005	6.6	<0.005	250	13.62	<1	1.8	No data	
	MC02	18/10/2012	15:24:00	25	3	16	0.464	0.15	0.1	0.15	0.25	<0.01	83	8.16	<0.005	7.35	<0.005	220	16.09	<1	1.6	Flow – flowing	
	MC02	4/02/2013	12:30:00																			Flow – dry	Not sampled completely dry
	MRAP8	11/10/2012	9:10:00	12	12	150		0.44	0.025	0.47	0.49	0.018			<0.005		<0.005			5	6.2	Flow – flowing	
	MCLEOD	16/10/2012	9:16:00	22	7	78	0.445	0.32	0.16	0.35	0.51	<0.01	82.5	8.5	0.007	7.38	<0.005	210	13.95	1	5.5	Flow – flowing	
	MC10	18/06/2012	15:56:00		7	38	0.63	0.29	1.1	0.29	1.4	0.013	82.3	8.49	<0.005	7.1	<0.005	300	13.85	<1	2.7	No data	
	MC10	18/10/2012	11:31:00	24	7	64	0.471	0.32	0.33	0.36	0.69	0.022	87.1	8.64	0.007	7.54	0.005	230	15.67	2	5.6	Flow – flowing	
	MC10	6/02/2013	9:28:00		5	18	5.53	0.73	2.5	0.8	3.3	0.066	84.6	7.08	0.008	6.82	<0.005	2980	23.21	1	1.5	Flow – stationary or static	No flow visible at site. Water clear
Rushy Creek	RRAP9	11/10/2012	14:45:00	31	10	120		0.54	0.046	0.57	0.62	0.027			0.013		<0.005			1	7.2	Flow – flowing	
	RRAP6	16/10/2012	15:04:00	29	7	42	0.598	0.36	0.097	0.38	0.48	0.019	85.3	8.24	0.006	6.74	0.005	290	16.91	1	6.1	Flow – flowing	
	RRAP10	16/10/2012	13:24:00	29	17	180	0.623	0.69	0.14	0.84	0.98	0.063	80.5	8.23	0.028	7.26	0.013	300	14.29	36	27	Flow – flowing	
	RUSHYCK	16/10/2012	14:57:00	26	8	56	0.522	0.44	0.31	0.49	0.81	0.02	97.7	8.63	0.01	7.49	<0.005	250	21.39	1	3.6	Flow – flowing	
Chapman Brook	CHAP12	19/06/2012	8:39:00		13	120	0.421	0.84	1	0.86	1.9	<0.01	66	6.65	0.041	6.55	<0.005	200	14.97	1	4.2	No data	
	CHAP12	18/10/2012	9:06:00	41	8	63	0.397	0.48	0.031	0.5	0.53	<0.01	63.1	6.49	0.01	6.53	<0.005	190	14.01	<1	5.3	Flow – flowing	
	CHAP12	4/02/2013	8:00:00																			Flow – dry	Not sampled completely dry
	CHAPX1	18/06/2012	17:08:00		3	18	0.447	0.12	1	0.12	1.1	<0.01	77.8	7.91	<0.005	7.02	<0.005	210	14.58	<1	1.2	No data	
	CHAPX1	23/10/2012	12:21:00	16	3	21	0.442	0.16	0.16	0.17	0.33	<0.01	82.9	8.17	<0.005	7.05	<0.005	210	15.99	<1	3.6	Flow – flowing	
Upper Chapman Brook	UCHAP1	17/10/2012	13:00:00																			Flow – dry	Site is dry
	UCHAP1	25/10/2012	13:45:00				0.382						19.3	1.84		5.49		180	17.43			Flow – stationary or static	Water quality not sampled. Herbicides sample taken only
	UCHAP1	4/02/2013	11:25:00																			Flow – dry	Not sampled completely dry
	UCHAPX2	19/06/2012	9:41:00		4	18	0.516	0.19	1	0.26	1.3	0.014	93.1	9.46	0.011	6.75	<0.005	250	14.56	2	3.6	No data	
	UCHAPX2	23/10/2012	14:11:00	10	2	12	0.418	0.15	0.055	0.18	0.24	0.013	87.1	7.85	<0.005	6.87	<0.005	200	20.36	<1	1.5	Flow – flowing	
	UCHAPX2	4/02/2013	9:34:00																			Flow – stationary or static	
	UCHAPX2	5/02/2013	9:34:00		2	68	0.542	<0.025	<0.01	0.19	0.2	0.11	11.4	1.04	0.005	6.49	<0.005	260	19.66	4	5.2	Flow – stationary or static	No flow visible at water quality sample location (some flow observed at riffles nearby). Oil sheen on surface – possibly eucalyptus oil.
	UCHAP5	19/06/2012	11:18:00		5	69	0.329	0.19	3.9	0.26	4.1	0.044	82	8.17	0.045	6.03	<0.005	160	15.54	32	30	No data	
	UCHAP5	25/10/2012	8:56:00	7	1	2	0.371	0.11	0.93	0.14	1.1	<0.01	90.8	9.48	<0.005	6.51	<0.005	180	13.37	<1	1	Flow – flowing	
	UCHAP5	5/02/2013	11:39:00		2	15	0.452	0.08	0.73	0.36	1.1	0.04	67.6	6.28	0.007	7.12	<0.005	220	18.76	1	2.5	Flow – stationary or static	No flow visible at water quality sample location (some flow observed at riffles nearby). Water clear
	UCHAP6	19/06/2012	10:25:00		3	19	0.513	0.092	1.3	0.074	1.4	0.016	71.4	7.22	0.007	6.75	<0.005	250	14.79	1	2.6	No data	
	UCHAP6	25/10/2012	15:49:00	10	2	8	0.43	0.1	0.16	0.16	0.32	0.025	84.1	7.99	<0.005	6.54	<0.005	210	17.8	<1	1.5	Flow – flowing	
Fisher Creek	FISHX3	19/06/2012	13:10:00		4	230	1.245	0.11	<0.01	0.13	0.14	0.022	37.6	3.8	<0.005	3.51	<0.005	610	14.84	1	1.9	No data	Orange floc'
	FISHX3	18/10/2012	14:22:00	3	1	<1	0.71	0.066	<0.01	0.071	0.08	<0.01	87.2	8.27	<0.005	5.9	<0.005	340	17.78	3	3.7	Flow – flowing	
	FISHX3	4/02/2013	12:00:00																			Flow – dry	Not sampled completely dry
Blackwood River	BLA15	18/06/2012	14:41:00		5	27	3.15	0.25	0.64	0.27	0.91	0.028	70.9	7.02	0.006	7.25	<0.005	1630	15.29	1	2.2	No data	
	BLA15	18/10/2012	13:17:00	69	8	23	5.05	0.44	0.049	0.49	0.54	<0.01	92.1	8.27	0.007	7.47	<0.005	2700	19.67	2	3.5	Flow – flowing	
	BLA15	6/02/2013	11:39:00		7	13	6.88	0.33	0.031	0.34	0.37	<0.01	96.6	7.74	0.005	7.9	<0.005	3770	25.33	1	1.1	Flow – flowing	Water clear
	BLA16	18/06/2012	15:12:00		5	30	3.26	0.23	0.68	0.28	0.96	0.031	69.8	6.91	0.009	7.05	<0.005	1690	15.28	<1	2.4	No data	
	BLA16	18/10/2012	13:01:00	68	8	27	4.97	0.42	0.13	0.43	0.56	<0.01	95.7	8.59	0.006	7.4	<0.005	2650	19.76	2	3.7	Flow – flowing	
	BLA16	6/02/2013	12:48:00		7	12	6.91	0.3	0.053	0.3	0.35	<0.01	93.7	7.55	0.005	7.61	<0.005	3780	25.03	1	1.1	Flow – flowing	Water clear
	BLA16X	6/02/2013	12:23:00		3	37	0.333	0.18	3	0.18	3.2	<0.01	85.6	8.3	<0.005	7.86	<0.005	160	16.78	2	2.5	Flow – flowing	Water clear, brackish

Key:

DOC (mg/L) *– Dissolved organic carbon is the amount of carbon made up of organic carbon that can pass through a 0.45 µm filter paper (therefore considered dissolved or soluble); expressed in milligrams per litre.*

Cond comp to 25 °C [in situ] (mS/cm) *– Electrical conductivity measured in situ using a held probe and expressed in milliSiemens per centimetre and compensated to a value that would occur if the water temperature were 25 °C (as conductivity is temperature dependent).*

D Org N (mg/L) – *Dissolved organic nitrogen is the amount of nitrogen made from organic nitrogen that can pass through a 0.45 µm filter paper (therefore considered dissolved or soluble); expressed in milligrams per litre.*

N0x [NO_2+NO_3] (mg/L) *– NOx is the amount of nitrogen in the sum of nitrate (NO_3) and nitrite (NO_2) that can pass through a 0.45 µm filter paper (therefore considered dissolved or soluble); expressed in milligrams per litre.*

TKN (mg/L) *– Total kjeldahl nitrogen is the amount of nitrogen in the sum of all organic nitrogen, ammonia and ammonium; it is an often calculated by subtracting the NOx from the TN rather than being measured analytically.*

TN (mg/L) *– Total nitrogen is the sum of all nitrogen in a sample; expressed in milligrams per litre.*

N as NH_3/NH_4 (mg/L) *– Nitrogen as ammonia/ammonium is the amount of nitrogen contained in the ammonia (NH_3) and ammonium (NH_4^+) in a sample; expressed in milligrams per litre.*

DO *– Dissolved oxygen is measured in situ and expressed either in mg/L or as a percentage of the maximum amount of dissolved oxygen the water can 'hold' at the temperature the water was at the time of sampling.*

TP (mg/L) *– Total phosphorus is the sum of all phosphorus in a sample; expressed in milligrams per litre.*

SRP (mg/L) *– Soluble reactive phosphorus (or orthophosphate) is the amount of phosphorus that can pass through a 0.45 µm filter paper (therefore considered dissolved or soluble); expressed in milligrams per litre.*

TSS (mg/L) *– Total suspended solids is a measure of the suspended particulate matter in a sample that is retained when passed through a filter of a nominal pore size (DoW specifies 0.45 µm filter paper); expressed in mg/L.*

Appendix M — Water quality data (pre-2012)

Table M1 Total nitrogen concentrations at sites MCLEOD and RUSHYCK, 2001–03 and 2011–12

River	Site	Total nitrogen concentration (mg/L) 2001–03 range (median)^n Winter Jun–Aug	Spring Sept–Nov	Summer Dec–Feb	2011–12 range (median)^n Winter Jun–Aug	Spring Sept–Nov	Summer Dec–Feb
McLeod Creek	MCLEOD (6091304)	0.08–1.40 (0.51) n=18	0.15–2.10 (0.49) n=14	0.44 n=1	0.77–0.89 (0.79) n=3	0.45–0.60 (0.53) n=2	0.75–1.90 (1.50) n=4
Rushy Creek	RUSHYCK (6091303)	0.28–1.60 (0.73) n=18	0.23–1.30 (0.57) n=14	0.43 n=1	1.30–2.00 (1.30) n=3	0.77–0.99 (0.89) n=4	1.10–1.60 (1.35) n=2

n = number of samples
Shading indicates total nitrogen concentration exceeded the guideline trigger value of 1.2 mg/L (ANZECC & ARMCANZ 2000a).
Source: Department of Water's Water Information Network – data available from http://wir.water.wa.gov.au/SitePages/SiteExplorer.aspx

Table M2 Total phosphorus concentrations at sites MCLEOD and RUSHYCK, 2001–03 and 2011–12

River	Site	Total phosphorus concentration (mg/L) 2001–03 range (median)^n Winter Jun–Aug	Spring Sept–Nov	Summer Dec–Feb	2011–12 range (median)^n Winter Jun–Aug	Spring Sept–Nov	Summer Dec–Feb
McLeod Creek	MCLEOD (6091304)	0.006–0.059 (0.021) n=14	0.006–0.120 (0.016) n=14	0.011 n=1	0.005–0.012 (0.009) n=2	0.009–0.016 (0.013) n=2	0.019–0.530 (0.062) n=4
Rushy Creek	RUSHYCK (6091303)	0.006–0.040 (0.024) n=17	0.006–0.100 (0.020) n=14	0.014 n=1	0.014–0.015 (0.015) n=3	0.010–0.025 (0.020) n=4	0.029-0.030 (0.030) n=2

n = number of samples
shading indicates that the turbidity exceeded the guideline trigger value of 0.065 mg/L (ANZECC & ARMCANZ 2000a).
Source: Department of Water's Water Information Network – data available from http://wir.water.wa.gov.au/SitePages/SiteExplorer.aspx

Table M3 Salinity concentrations at sites MCLEOD and RUSHYCK, 2001–03 and 2011–12

		Electrical conductivity (µS/cm) *					
		2001–03 range (median)^n			**2011–12 range (median)^n**		
River	**Site**	Winter Jun–Aug	Spring Sept–Nov	Summer Dec–Feb	Winter Jun–Aug	Spring Sept–Nov	Summer Dec–Feb
McLeod Creek	MCLEOD (6091304)	64.8-901.0 (445.0) $^{n=12}$	93.1-451.0 (358.0) $^{n=13}$	110.8 n = 1	333.6-353.8 (353.5) $^{n=3}$	389.8-429.8 (409.8) $^{n=2}$	250.5-419.3 (334.9) $^{n=2}$
Rushy Creek	RUSHYCK (6091303)	84.5-1170.0 (591.5) $^{n=12}$	128.7-690.0 (499.0) $^{n=12}$	160.8 n = 1	425.1-529.6 (458.7) $^{n=3}$	346.9-492.0 (370.2) $^{n=3}$	609.8 n=1

** = EC uncompensated for temperature*

n = number of samples

Source: Department of Water's Water Information Network – data available from http://wir.water.wa.gov.au/SitePages/SiteExplorer.aspx

Appendix N — Bioavailable metals analysis

Site ref no.	**Date collected**	**Aluminium mg/kg**	**Arsenic mg/kg**	**Cadmium mg/kg**	**Chromium mg/kg**	**Copper mg/kg**	**Iron mg/kg**	**Lead mg/kg**	**Mercury mg/kg**	**Silver mg/kg**	**Zinc mg/kg**
ANZECC guideline	ISQG Low	n.a.	20	1.5	80	65	n.a.	50	0.15	1	200
ANZECC guideline	ISQG High	n.a.	70	10	370	270	n.a.	220	1	3.7	410
UCHAP1	25-Oct-12	8150	<0.5	<0.5	2.8	6.2	6000	45	<0.2	<0.5	6.2
UCHAP6	25-Oct-12	3220	<0.5	<0.5	0.95	4.4	7390	24	<0.2	<0.5	39
UCHAP5	25-Oct-12	1600	<0.5	<0.5	0.85	1.4	2890	8.2	<0.2	<0.5	6.5
CHAP12	18-Oct-12	2200	<0.5	<0.5	0.63	5.3	52100	9.8	<0.2	<0.5	21

Bioavailable metals are extracted from sediment using a cold dilute acid extraction. This is designed to extract only metals loosely bound to the surface of sediment particles, rather than those tightly bound in the mineral matrix (ANZECC & ARMCANZ 2000a). This is considered to provide an approximation of the metals that are biologically available.

Appendix O — Organochlorine pesticides analysis

Site code	Date collected	HCB mg/kg	Heptachlor mg/kg	Heptachlor epoxide mg/kg	Aldrin mg/kg	gamma-BHC (Lindane) mg/kg	alpha-BHC mg/kg	beta-BHC mg/kg	delta-BHC mg/kg	trans-Chlordane mg/kg	cis-Chlordane mg/kg	Oxychlordane mg/kg	Dieldrin mg/kg
UCHAP1	25-Oct-12	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
UCHAP6	25-Oct-12	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
UCHAP5	25-Oct-12	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CHAP12	18-Oct-12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LAB QA SITE	Recovery (%)		98		105	90							97
LAB QA SITE	Blank	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Site code	Date collected	pp-DDE mg/kg	pp-DDD mg/kg	pp-DDT mg/kg	Endrin mg/kg	Endrin Aldehyde mg/kg	Endrin Ketone mg/kg	alpha-Endosulfan mg/kg	beta-Endosulfan mg/kg	Endosulfan Sulfate mg/kg	Methoxychlor mg/kg	Surrogate: DF-DDE %REC
UCHAP1	25-Oct-12	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	71
UCHAP6	25-Oct-12	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	73
UCHAP5	25-Oct-12	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	79
CHAP12	18-Oct-12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	102
LAB QA SITE	Recovery (%)			103	104							95
LAB QA SITE	Blank	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	

Appendix P — Organophosphate pesticides analysis

Site code	Date collected	Dichlorvos mg/kg	Demeton-S-Methyl mg/kg	Diazinon mg/kg	Dimethoate mg/kg	Chlorpyrifos mg/kg	Chlorpyrifos Methyl mg/kg	Malathion mg/kg	Fenthion mg/kg	Ethion mg/kg	Fenitrothion mg/kg	Chlorfenvinphos (E) mg/kg
UCHAP 1	25-Oct-12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
UCHAP 6	25-Oct-12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
UCHAP 5	25-Oct-12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CHAP12	18-Oct-12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LAB QA SITE	Recovery (%)			101		120				122		
LAB QA SITE	Blank	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Site code	Date collected	Chlorfenvinphos (Z) mg/kg	Parathion (Ethyl) mg/kg	Parathion Methyl mg/kg	Pirimiphos Methyl mg/kg	Pirimiphos Ethyl mg/kg	Azinphos Methyl mg/kg	Azinphos Ethyl mg/kg	Surrogate: TPP %REC
UCHAP1	25-Oct-12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	113
UCHAP6	25-Oct-12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	106
UCHAP5	25-Oct-12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	105
CHAP12	18-Oct-12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	122
LAB QA SITE	Recovery (%)		104						98
LAB QA SITE	Blank	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	

Appendix Q — Particle size analysis

Site code	Clay 0–4 µm	Silt 4–62 µm	Fine sand 62–250 µm	Medium sand 250–500 µm	Coarse sand 500–2000 µm	Gravel 2000–10000 µm
UCHAP6	15.28	37.17	19.45	5.99	10.90	11.20
UCHAP5	9.47	28.04	30.08	27.71	3.90	0.80
UCHAP1	10.72	38.90	22.91	4.67	13.90	8.90
CHAP12	3.69	17.21	9.27	3.13	32.20	34.50

Shaded boxes highlight dominant fraction

Appendix R — Herbicides analysis

Table R1 Phenoxy Acid Herbicide Suite

Site code	Date collected	Dicamba ug/L	MCPA ug/L	Dichlorprop ug/L	2,4-D ug/L	2,4,5-T ug/L	2,4,5-TP ug/L	2,4-DB ug/L	MCPP ug/L	Triclopyr ug/L	Picloram ug/L	Clopyralid ug/L	Fluroxypyr ug/L
UCHAP1	25-Oct-12	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
UCHAP6	25-Oct-12	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
UCHAP5	25-Oct-12	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CHAP12	18-Oct-12	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
LAB QA SITE	Recovery (%)	102	102	101	101	102	104	107	103	104			101
LAB QA SITE	Blank	<1	<1	<1	<1	<1	<1	<1	<1	<1			<1
LAB QA SITE	Recovery (%)	102	102	101	101	102	104	107	103	104			101
LAB QA SITE	Blank	<1	<1	<1	<1	<1	<1	<1	<1	<1			<1

Table R2 Non-organochlorine and non-organophosphate herbicides

Site code	Date collected	Atrazine ug/L	Diuron ug/L	Hexazinone ug/L	Linuron ug/L	Metolachlor ug/L	Molinate ug/L	Oxyfluorfen ug/L	Pendimethalin ug/L	Prometryn ug/L	Simazine ug/L	Trifluralin ug/L
UCHAP1	25-Oct-12	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
UCHAP6	25-Oct-12	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
UCHAP5	25-Oct-12	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
CHAP12	18-Oct-12	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
LAB QA SITE	Recovery (%)	96										
LAB QA SITE	Blank	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1

Appendix S — Fish distribution in the study area

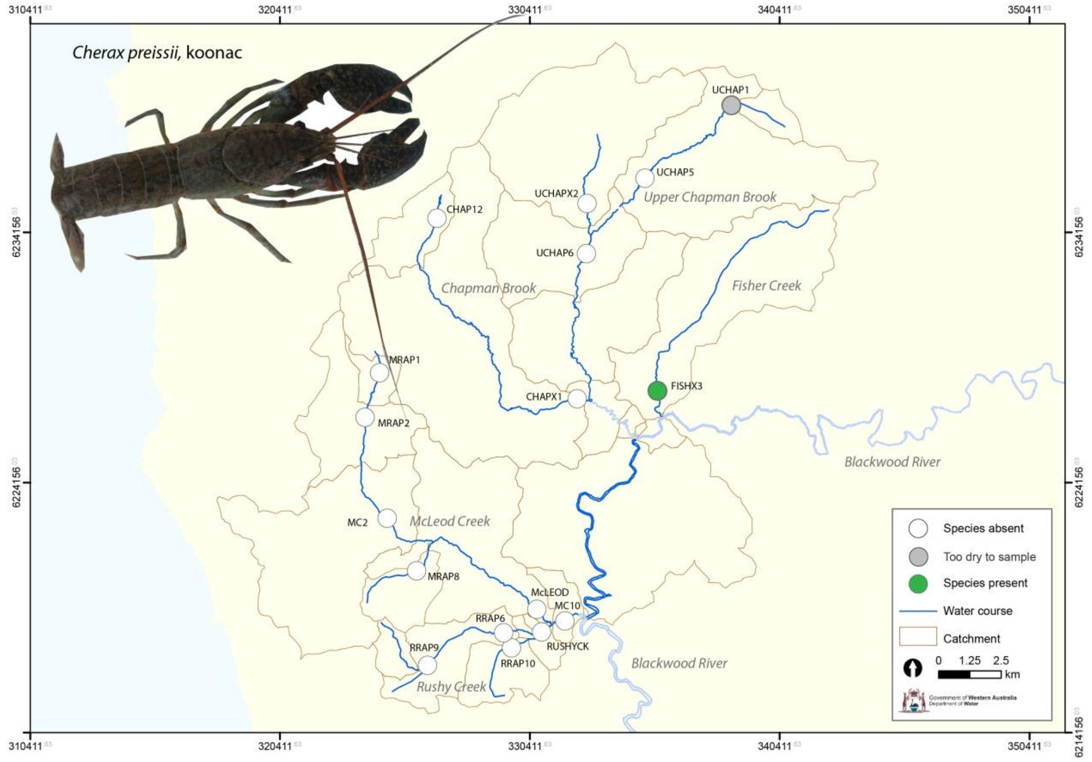


Figure S1 Distribution of Cherax preissii in October 2012

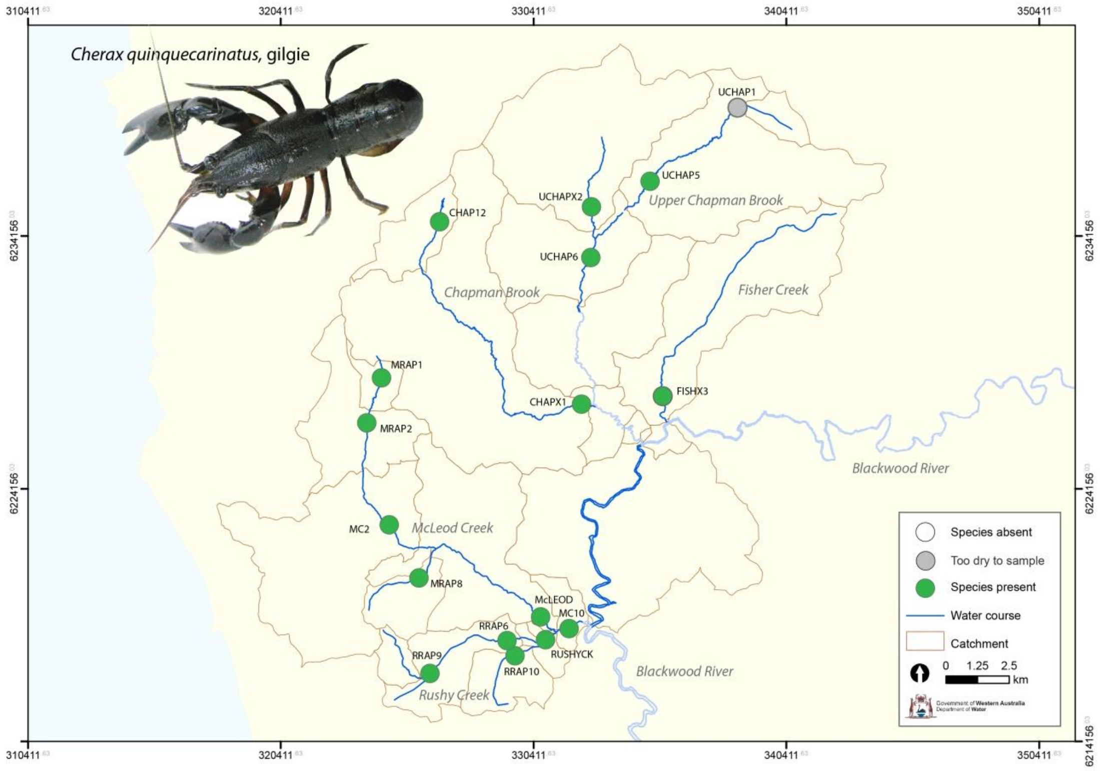


Figure S2 Distribution of Cherax quiquecarinatus in October 2012

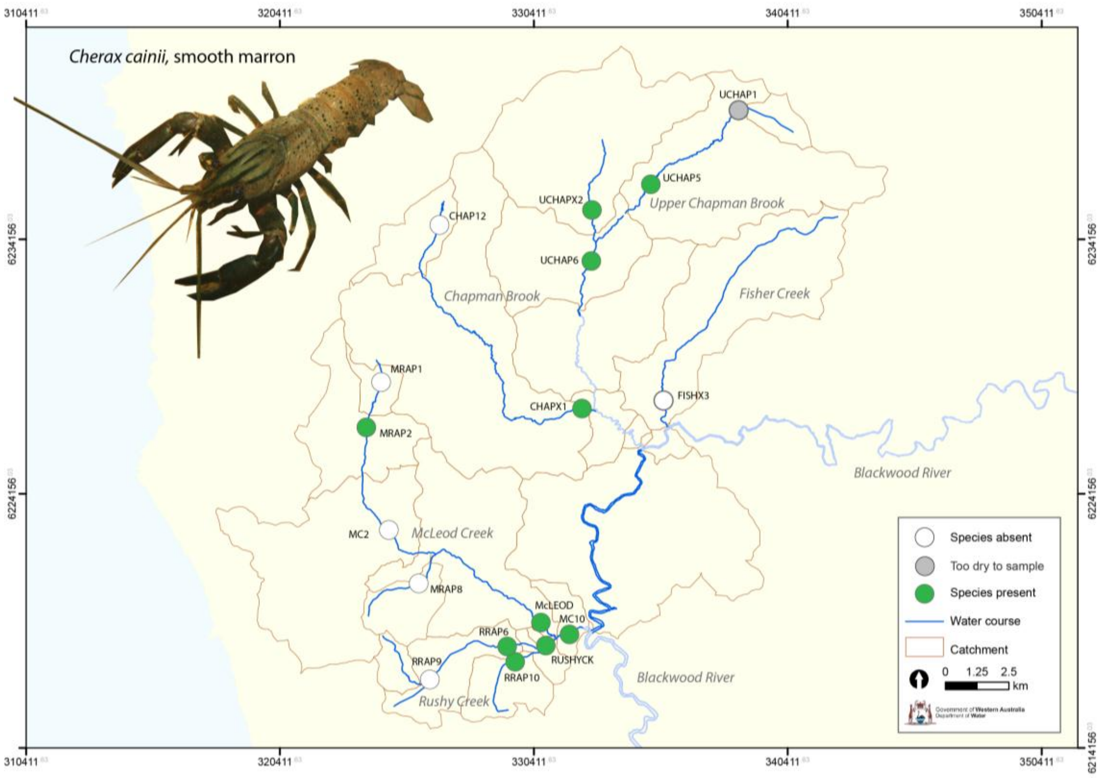


Figure S3 Distribution of Cherax cainii in October 2012

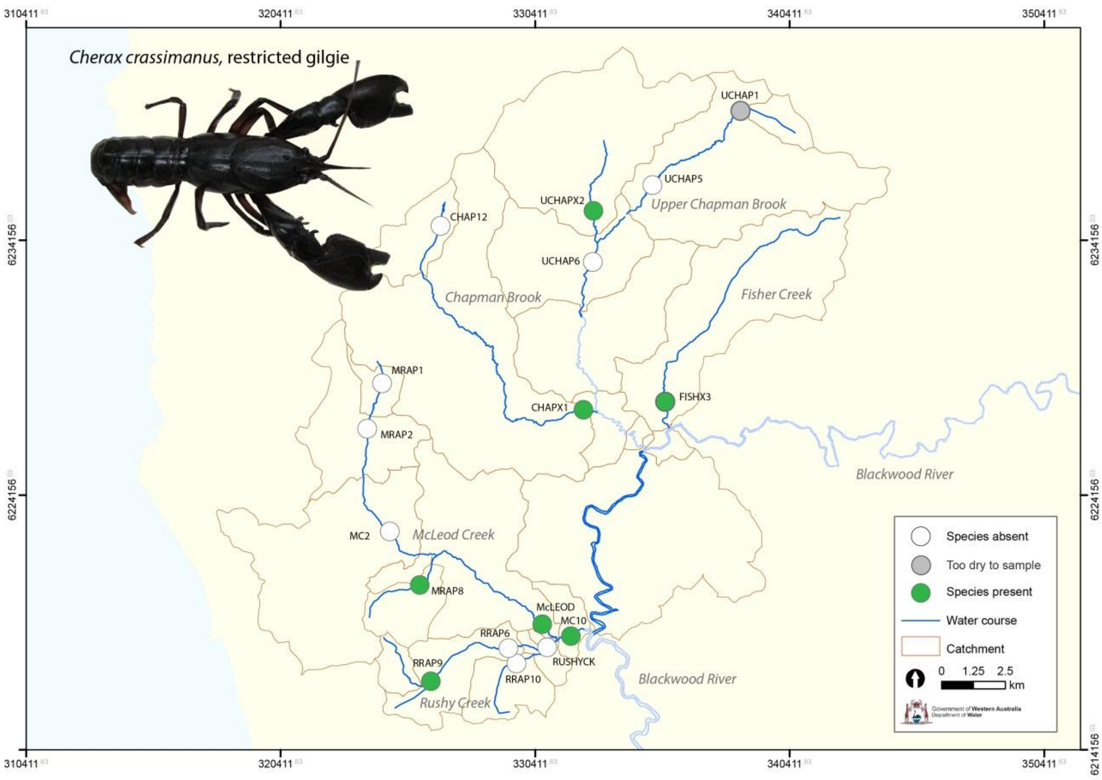


Figure S4 Distribution of Cherax crassimanus in October 2012

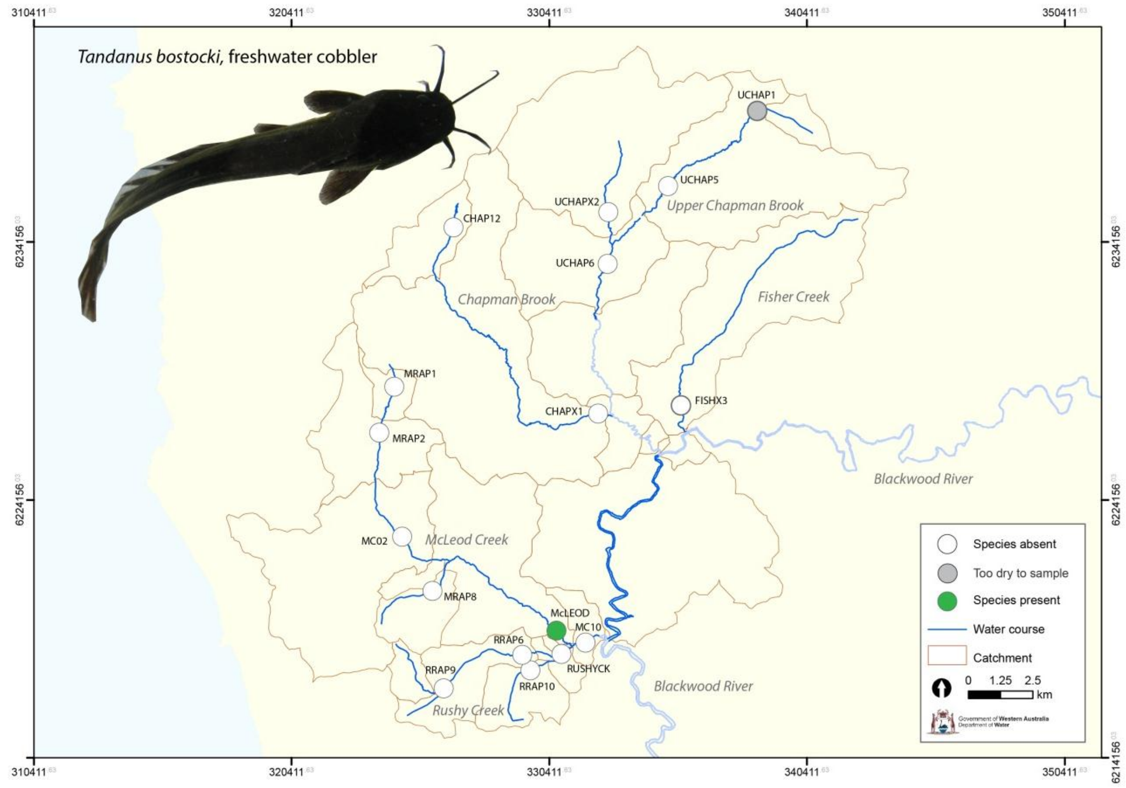


Figure S5 Distribution of Tandanus bostocki in October 2012

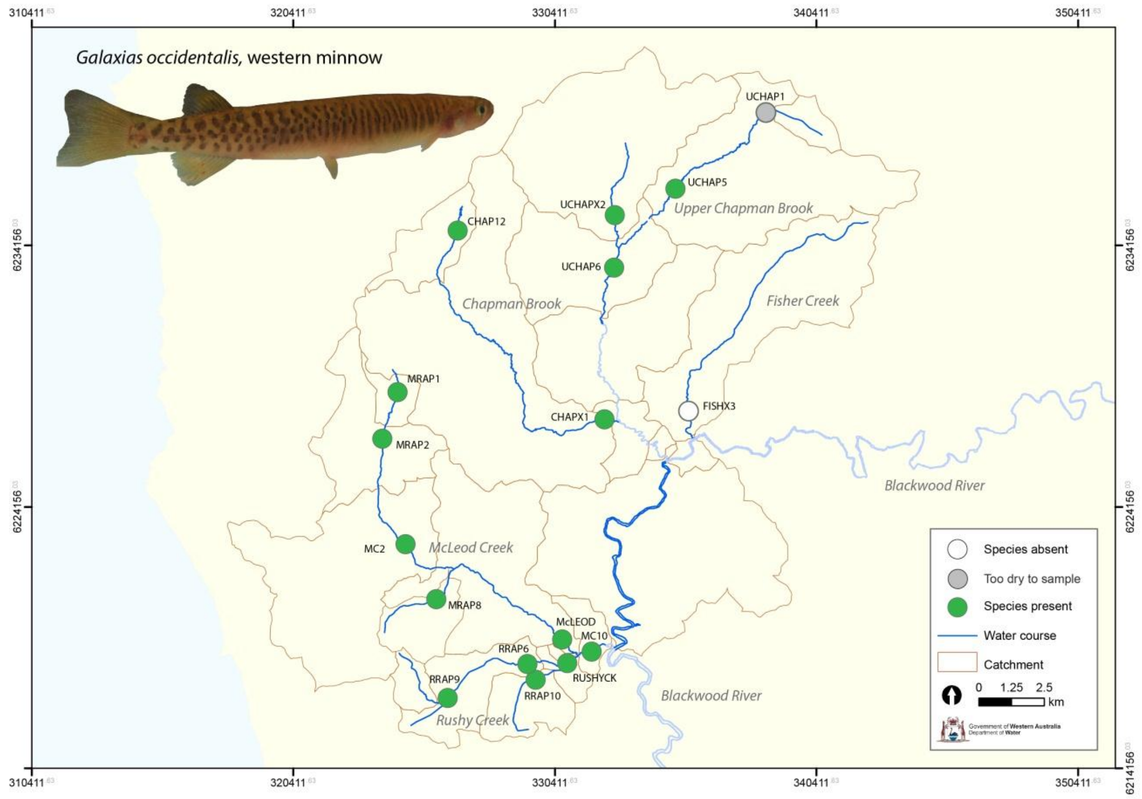


Figure S6 Distribution of Galaxias occidentalis in October 2012

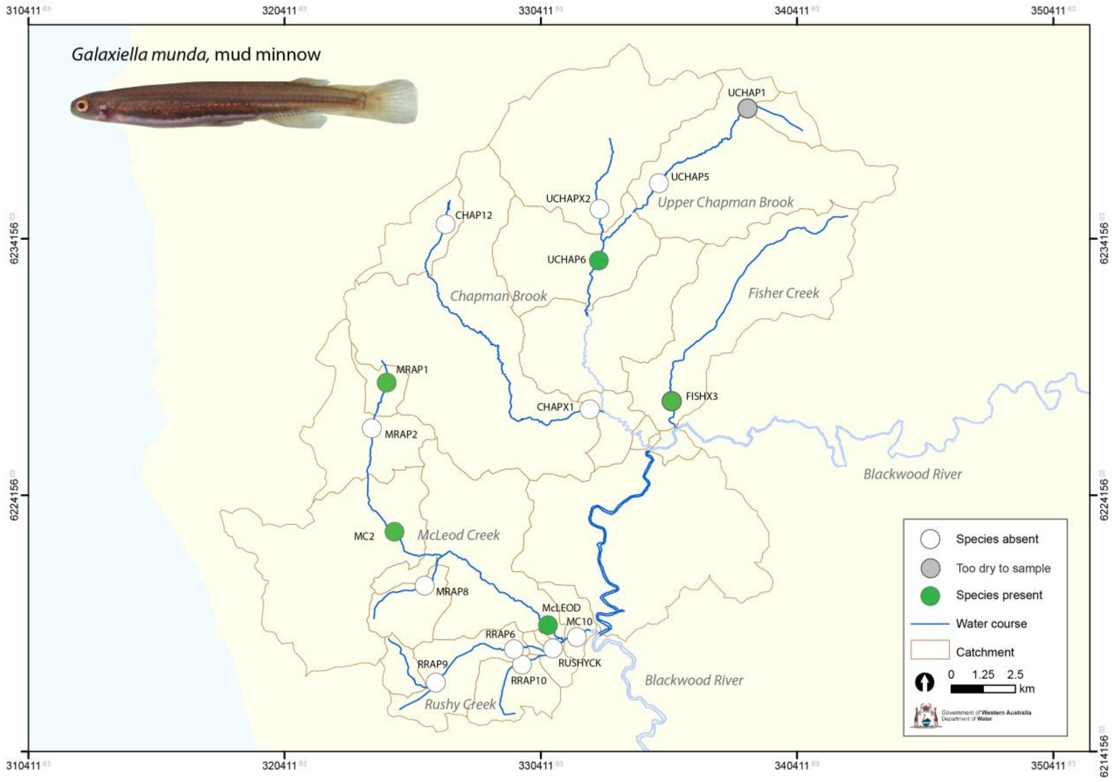


Figure S7 *Distribution of Galaxiella munda in October 2012*

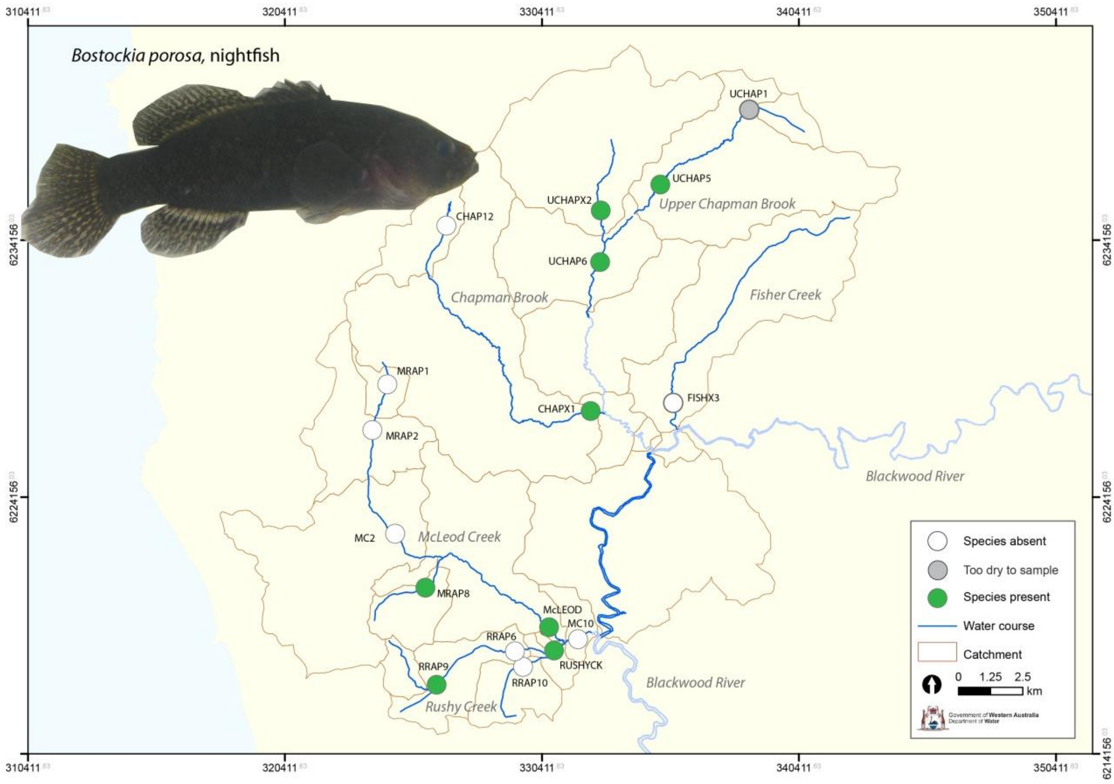


Figure S8 *Distribution of Bostockia porosa in October 2012*

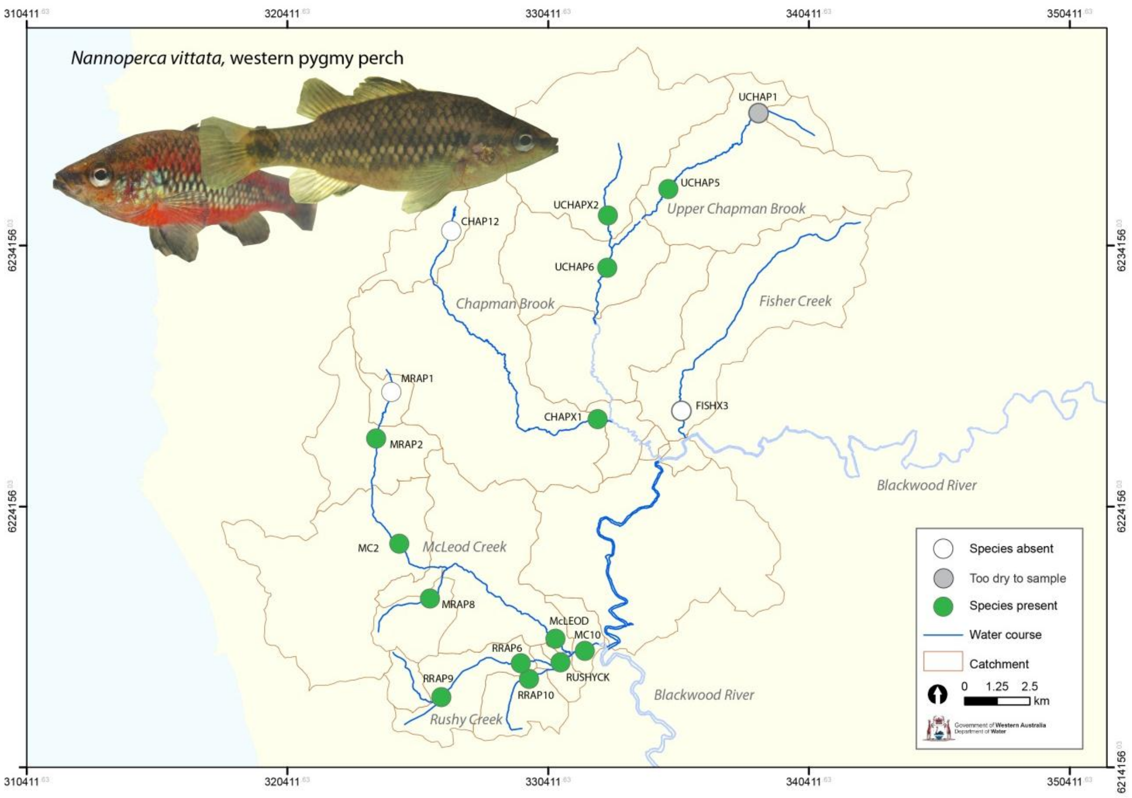


Figure S9 Distribution of Nannoperca vittata in October 2012

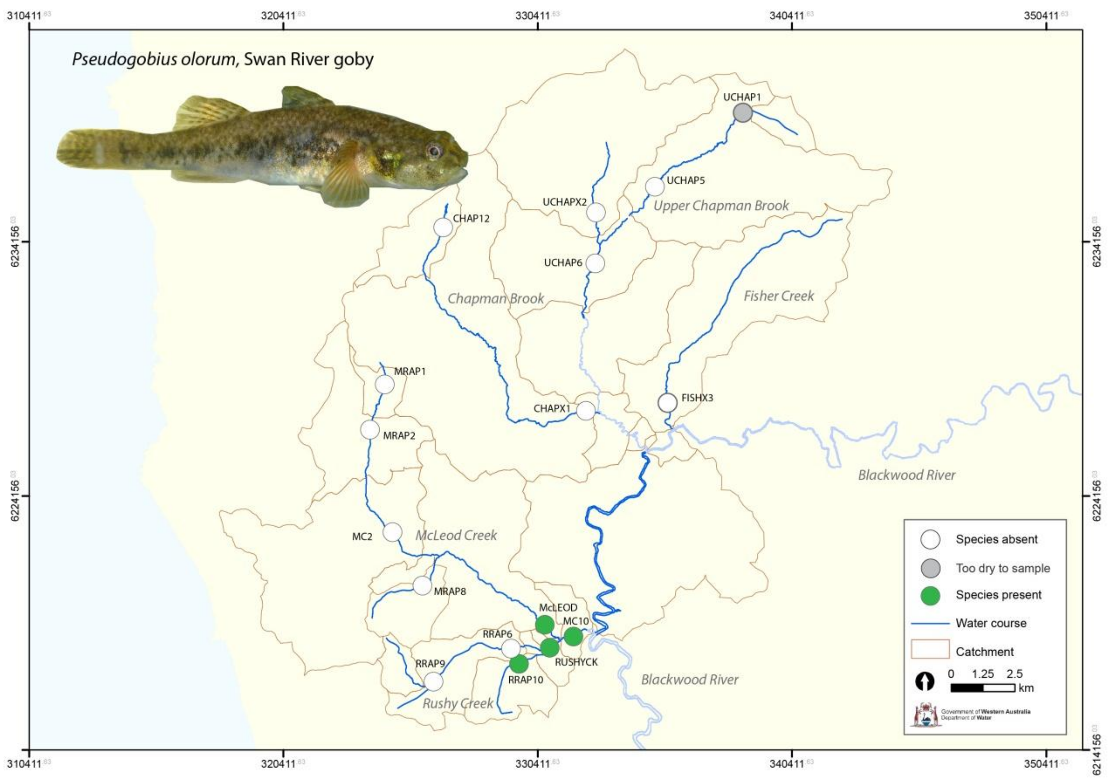


Figure S10 Distribution of Pseudogobius olorum October 2012

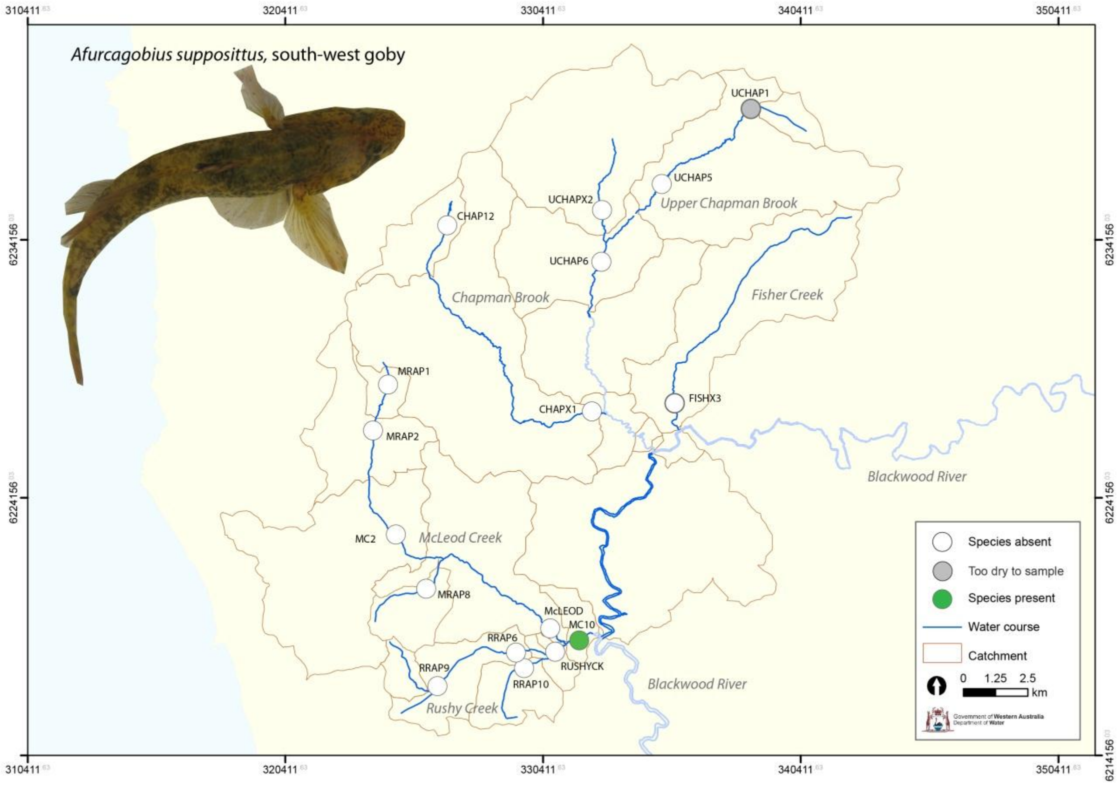


Figure S11 Distribution of Afurcagobius suppositus in October 2012

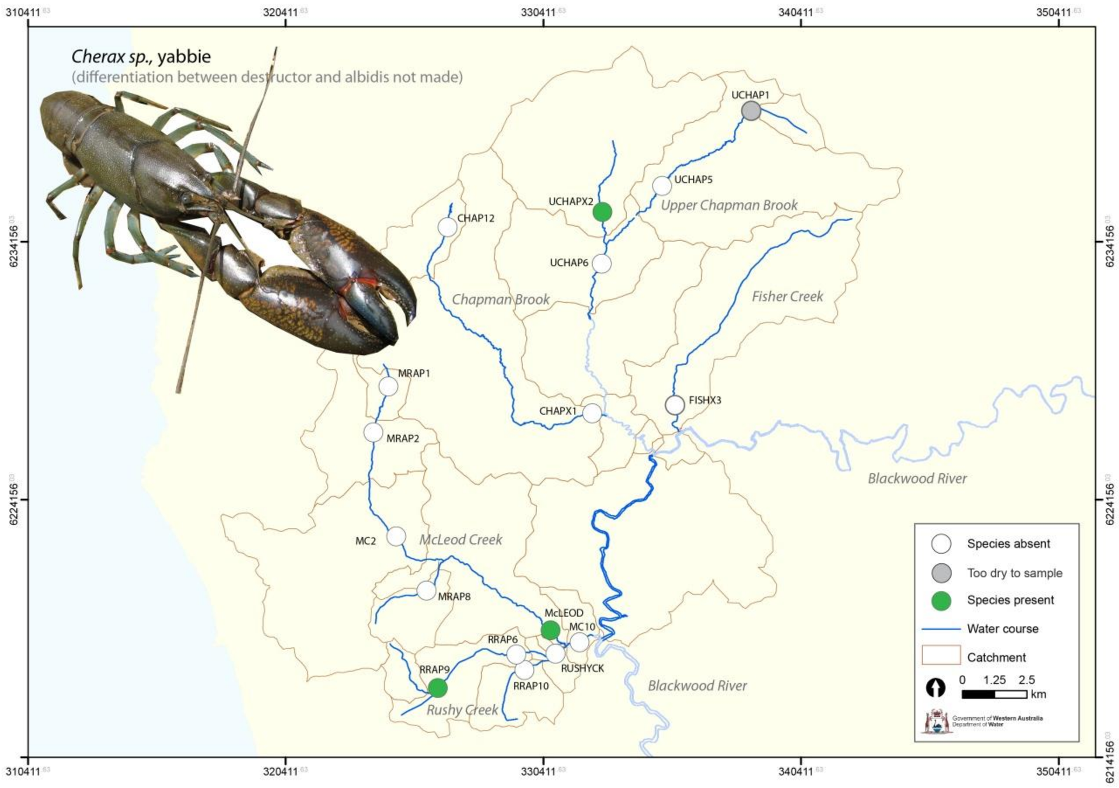


Figure S12 Distribution of yabby (Cherax spp.) in October 2012

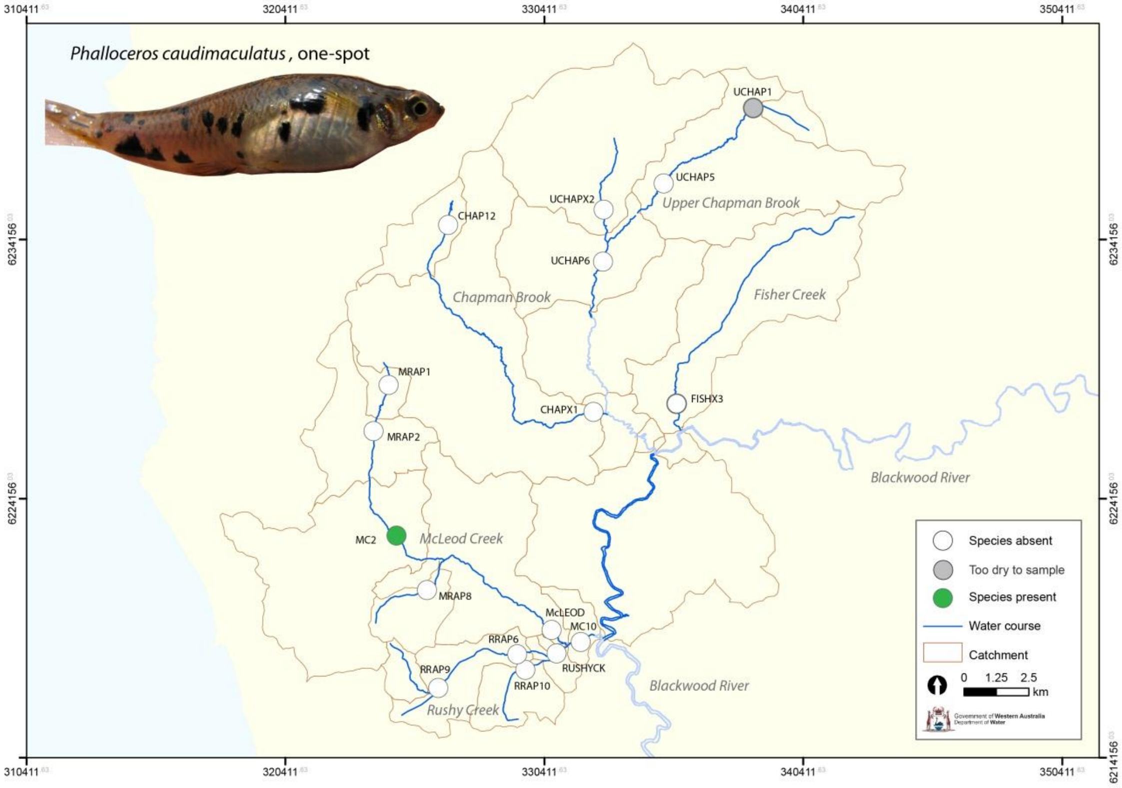


Figure S13 Distribution of Phalloceros caudimaculatus in October 2012

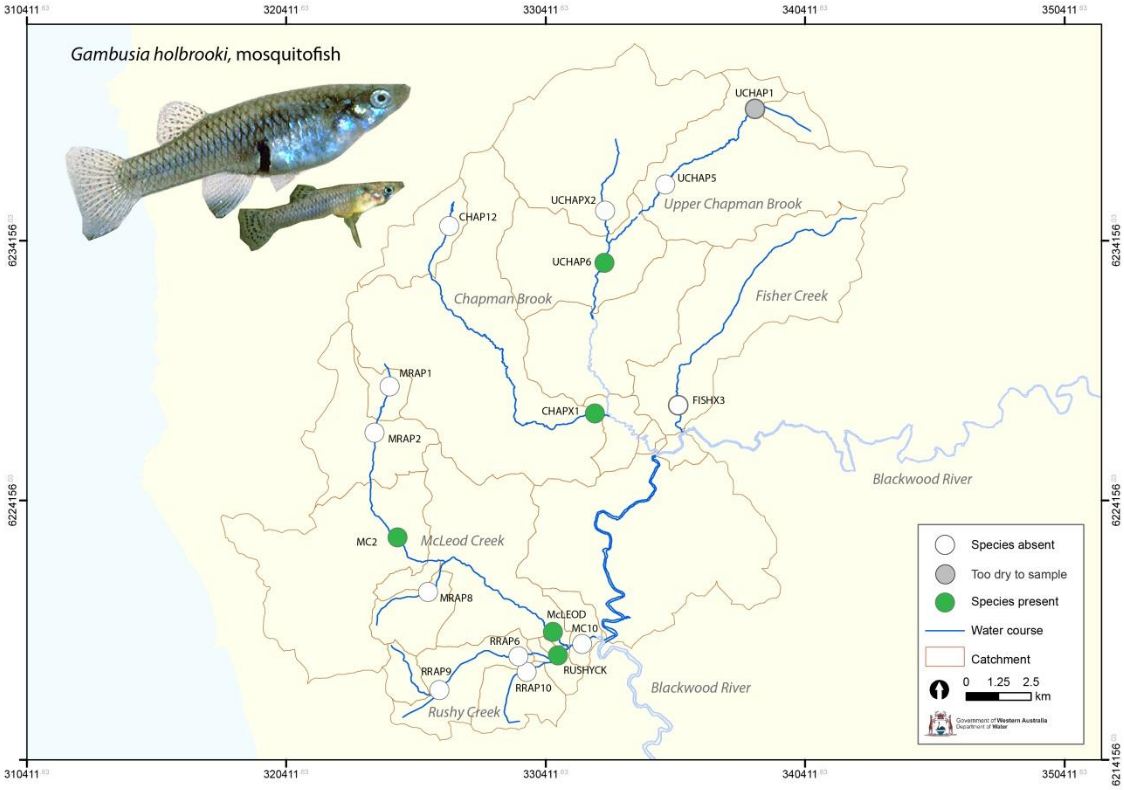


Figure S14 Distribution of Gambusia holbrooki in October 2012

Appendix T — Fish and crayfish abundance, October 2012

	Site code	MRAP1	MRAP2	MC02	MRAP8	MCLEOD	MC10	RRAP9	RRAP6	RRAP10	RUSHYCK	CHAP12	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Latin name	**Common name**																	
Native fish and crayfish species																		
Galaxias occidentalis	Western minnow	73	50	28	26	42	17	162	184	2105	196	2	40	dry	74	26	80	0
Galaxiella munda	Mud minnow	14	0	17	4	2	0	0	0	0	0	0	0	dry	0	0	6	13
Nannoperca vittata	Western pygmy perch	0	29	13	12	20	185	117	37	8	79	0	3	dry	142	66	39	0
Pseudogobius olorum	Swan river goby	0	0	0	0	2	1	0	0	1	44	0	0	dry	0	0	0	0
Afurcagobius suppositus	South-western goby	0	0	0	0	0	7	0	0	0	0	0	0	dry	0	0	0	0
Bostockia porosa	Nightfish	0	0	0	3	3	0	1	0	0	2	0	3	dry	4	4	5	0
Tandanus bostocki	Freshwater cobbler	0	0	0	0	1	0	0	0	0	0	0	0	dry	0	0	0	0
Geotria australis	Pouched lamprey	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Leptatherina wallacei	Western hardyhead	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Cherax cainii	Smooth marron	0	15	0	0	2	1	0	2	1	2	0	1	dry	3	5	6	0
Cherax quinquecarinatus	Gilgie	14	1	50	12	9	52	23	7	44	2	28	29	dry	10	27	24	48
Cherax crassimanus	Gilgie restricted	0	0	0	6	2	15	4	0	0	0	0	4	dry	4	0	0	12
Cherax preissi	Koonac	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	1
Exotic fish and crayfish species																		
Phalloceros caudimaculatus	One-spot live bearer	0	0	1	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Gambusia holbrooki	Eastern mosquitofish	0	0	70	0	7	0	0	0	0	5	0	1	dry	0	0	3	0
Cherax spp.	Yabby	0	0	0	0	0	0	2	0	0	5	0	0	dry	2	0	0	0

	Site code	MRAP1	MRAP2	MC02	MRAP8	MCLEOD	MC10	RRAP9	RRAP6	RRAP10	RUSHYCK	CHAP12	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Latin name	**Common name**																	
Nativeness calculations																		
# native species		3	4	4	6	9	7	5	4	5	6	2	6	dry	6	5	6	4
# exotic species		0	0	2	0	1	0	1	0	0	2	0	1	dry	1	0	1	0
Abundance native species		101	95	108	63	83	278	307	230	2159	325	30	80	dry	237	128	160	74
Total abundance		101	95	179	63	90	278	309	230	2159	335	30	81	dry	239	128	163	74
Additional species observed																		
Palaemonetes australis	Freshwater shrimp	0	0	0	0	10	85	0	0	0	0	0	0	dry	0	0	1	0
Chelodina oblonga	Long-neck turtle	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Unidentified sp. (likely motorbike frog)	Tadpole	538	0	71	2	7	0	9	0	5	10	6	1	dry	2	0	3	0

Note: fish sampling was not conducted at sites on the Blackwood River due to the size of the channel.

Appendix U — Fish and crayfish abundance, February 2013

	Site code	MRAP1	MRAP2	MC02	MRAP8	MCLEOD	MC10	RRAP9	RRAP6	RRAP10	RUSHYCK	CHAP12	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Latin name	**Common name**																	
Native fish and crayfish species																		
Galaxias occidentalis	Western minnow	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	143	16	dry	dry
Galaxiella munda	Mud minnow	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	20	dry	dry
Nannoperca vittata	Western pygmy perch	n/a	n/a	dry	n/a	n/a	286	n/a	n/a	n/a	n/a	dry	dry	dry	212	20	dry	dry
Pseudogobius olorum	Swan river goby	n/a	n/a	dry	n/a	n/a	6	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Afurcagobius suppositus	South-western goby	n/a	n/a	dry	n/a	n/a	75	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Bostockia porosa	Nightfish	n/a	n/a	dry	n/a	n/a	3	n/a	n/a	n/a	n/a	dry	dry	dry	20	14	dry	dry
Tandanus bostocki	Freshwater cobbler	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Geotria australis	Pouched lamprey	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	2	dry	dry
Leptatherina wallacei	Western hardyhead	n/a	n/a	dry	n/a	n/a	401	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax cainii	Smooth marron	n/a	n/a	dry	n/a	n/a	1	n/a	n/a	n/a	n/a	dry	dry	dry	6	1	dry	dry
Cherax quinquecarinatus	Gilgie	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	3	1	dry	dry
Cherax crassimanus	Gilgie restricted	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	3	0	dry	dry
Cherax preissi	Koonac	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Exotic fish and crayfish species																		
Phalloceros caudimaculatus	One-spot live bearer	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Gambusia Holbrooki	Gambusia	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax spp.	Yabby	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry

	Site code	MRAP1	MRAP2	MC02	MRAP8	MCLEOD	MC10	RRAP9	RRAP6	RRAP10	RUSHYCK	CHAP12	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Latin name	**Common name**																	
Nativeness calculations																		
# native species*		n/a	n/a	dry	n/a	n/a	6	n/a	n/a	n/a	n/a	dry	dry	dry	6	7	dry	dry
# exotic species		n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
abundance native species		n/a	n/a	dry	n/a	n/a	772	n/a	n/a	n/a	n/a	dry	dry	dry	387	74	dry	dry
total abundance		n/a	n/a	dry	n/a	n/a	772	n/a	n/a	n/a	n/a	dry	dry	dry	387	74	dry	dry
Additional species observed																		
Palaemonetes australis	Freshwater shrimp	n/a	n/a	dry	n/a	n/a	71	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Chelodina oblonga	Long-neck turtle	n/a	n/a	dry	n/a	n/a	7	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Unidentified sp. (likely motorbike frog)	Tadpole	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry

** The calculation of total number of native species includes Leptatherina wallacei (Western hardyhead), however this species is not included in the calculation of the fish and crayfish index score.*

Fish sampling was not conducted at sites on the Blackwood River due to the size of the channel.

Appendix V — Fish and crayfish species age structure, October 2012

Native fish and crayfish species		Site code	MRAP1	MRAP2	MC02	MRAP8	MCLEOD	MC10	RRAP9	RRAP6	RRAP10	RUSHYCK	CHAP12	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Latin name	**Common name**	**Size class**																	
Galaxias occidentalis	Western minnow	0-20	30	0	0	0	0	16	0	0	0	0	0	0	dry	2	0	0	0
Galaxias occidentalis	Western minnow	20-50	40	22	14	1	25	0	33	27	38	118	2	23	dry	29	5	53	0
Galaxias occidentalis	Western minnow	50-100	3	21	14	25	17	1	126	136	2022	76	0	15	dry	37	13	24	0
Galaxias occidentalis	Western minnow	100+	0	7	0	0	0	0	3	21	45	2	0	2	dry	6	8	3	0
Galaxiella munda	Mud minnow	0-20	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	9
Galaxiella munda	Mud minnow	20-50	14	0	17	4	2	0	0	0	0	0	0	0	dry	0	0	6	4
Galaxiella munda	Mud minnow	50-100	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Galaxiella munda	Mud minnow	100+	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Nannoperca vittata	Western pygmy perch	0-20	0	0	0	0	0	15	5	0	0	0	0	0	dry	2	0	0	0
Nannoperca vittata	Western pygmy perch	20-50	0	26	13	10	20	170	112	37	8	79	0	3	dry	133	62	39	0
Nannoperca vittata	Western pygmy perch	50-100	0	3	0	2	0	0	0	0	0	0	0	0	dry	7	4	0	0
Nannoperca vittata	Western pygmy perch	100+	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Pseudogobius olorum	Swan river goby	0-20	0	0	0	0	0	1	0	0	0	1	0	0	dry	0	0	0	0
Pseudogobius olorum	Swan river goby	20-50	0	0	0	0	0	0	0	0	1	38	0	0	dry	0	0	0	0
Pseudogobius olorum	Swan river goby	50-100	0	0	0	0	2	0	0	0	0	5	0	0	dry	0	0	0	0
Pseudogobius olorum	Swan river goby	100+	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Afurcagobius suppositus	South-western goby	0-20	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Afurcagobius suppositus	South-western goby	20-50	0	0	0	0	0	1	0	0	0	0	0	0	dry	0	0	0	0
Afurcagobius suppositus	South-western goby	50-100	0	0	0	0	0	6	0	0	0	0	0	0	dry	0	0	0	0
Afurcagobius suppositus	South-western goby	100+	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0

Native fish and crayfish species		Site code	MRAP1	MRAP2	MC02	MRAP8	MCLEOD	MC10	RRAP9	RRAP6	RRAP10	RUSHYCK	CHAP12	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Latin name	**Common name**	**Size class**																	
Bostockia porosa	Nightfish	0-20	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Bostockia porosa	Nightfish	20-50	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Bostockia porosa	Nightfish	50-100	0	0	0	3	1	0	0	0	0	2	0	1	dry	2	2	2	0
Bostockia porosa	Nightfish	100+	0	0	0	0	2	0	1	0	0	0	0	2	dry	2	2	3	0
Tandanus bostocki	Freshwater cobbler	0-100	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Tandanus bostocki	Freshwater cobbler	100-200	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Tandanus bostocki	Freshwater cobbler	200-400	0	0	0	0	1	0	0	0	0	0	0	0	dry	0	0	0	0
Tandanus bostocki	Freshwater cobbler	400+	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Geotria australis	Pouched lamprey	0-100	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Geotria australis	Pouched lamprey	100-200	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Geotria australis	Pouched lamprey	200-400	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Geotria australis	Pouched lamprey	400+	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Leptatherina wallacei	Western hardyhead	0-20	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Leptatherina wallacei	Western hardyhead	20-50	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Leptatherina wallacei	Western hardyhead	50-100	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Leptatherina wallacei	Western hardyhead	100+	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Cherax cainii	Smooth marron	0-20	0	0	0	0	0	0	0	0	1	0	0	0	dry	0	0	3	0
Cherax cainii	Smooth marron	20-50	0	3	0	0	0	0	0	2	0	2	0	1	dry	1	0	3	0
Cherax cainii	Smooth marron	50-76	0	9	0	0	2	1	0	0	0	0	0	0	dry	2	4	0	0
Cherax cainii	Smooth marron	76-100	0	3	0	0	0	0	0	0	0	0	0	0	dry	0	1	0	0
Cherax cainii	Smooth marron	100+	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0

Native fish and crayfish species		Site code	MRAP1	MRAP2	MC02	MRAP8	MCLEOD	MC10	RRAP9	RRAP6	RRAP10	RUSHYCK	CHAP12	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Latin name	**Common name**	**Size class**																	
Cherax quinquecarinatus	Gilgie	0-20	8	0	3	2	0	0	7	0	32	0	2	1	dry	0	0	3	12
Cherax quinquecarinatus	Gilgie	20-50	4	1	47	10	9	44	15	5	7	1	26	28	dry	10	27	21	32
Cherax quinquecarinatus	Gilgie	50-100	2	0	0	0	0	8	1	2	5	1	0	0	dry	0	0	0	4
Cherax quinquecarinatus	Gilgie	100+	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Cherax crassimanus	Gilgie restricted	0-20	0	0	0	0	0	1	0	0	0	0	0	0	dry	0	0	0	2
Cherax crassimanus	Gilgie restricted	20-50	0	0	0	6	2	12	3	0	0	0	0	4	dry	4	0	0	10
Cherax crassimanus	Gilgie restricted	50-100	0	0	0	0	0	2	1	0	0	0	0	0	dry	0	0	0	0
Cherax crassimanus	Gilgie restricted	100+	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Cherax preissi	Koonac	0-20	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Cherax preissi	Koonac	20-50	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	1
Cherax preissi	Koonac	50-100	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Cherax preissi	Koonac	100+	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Exotic fish and crayfish species																			
Phalloceros caudimaculatus	One-spot live bearer	0-20	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Phalloceros caudimaculatus	One-spot live bearer	20-50	0	0	1	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Phalloceros caudimaculatus	One-spot live bearer	50-100	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Phalloceros caudimaculatus	One-spot live bearer	100+	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Gambusia holbrooki	Gambusia	0-20	0	0	1	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Gambusia holbrooki	Gambusia	20-50	0	0	69	0	7	0	0	0	0	4	0	1	dry	0	0	3	0
Gambusia holbrooki	Gambusia	50-100	0	0	0	0	0	0	0	0	0	1	0	0	dry	0	0	0	0
Gambusia holbrooki	Gambusia	100+	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0

Native fish and crayfish species		Site code	MRAP1	MRAP2	MC02	MRAP8	MCLEOD	MC10	RRAP9	RRAP6	RRAP10	RUSHYCK	CHAP12	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Latin name	**Common name**	**Size class**																	
Cherax spp.	Yabby	0-20	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Cherax spp.	Yabby	20-50	0	0	0	0	0	0	2	0	0	5	0	0	dry	2	0	0	0
Cherax spp.	Yabby	50-100	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0
Cherax spp.	Yabby	100+	0	0	0	0	0	0	0	0	0	0	0	0	dry	0	0	0	0

Appendix W — Fish and crayfish species age structure, February 2013

Native fish and crayfish species		Site code	MRAP1	MRAP2	MC02	MRAP8	MCLEOD	MC10	RRAP9	RRAP6	RRAP10	RUSHYCK	CHAP12	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Latin name	**Common name**	**Size class**																	
Galaxias occidentalis	Western minnow	0-20	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	1	0	dry	dry
Galaxias occidentalis	Western minnow	20-50	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	24	0	dry	dry
Galaxias occidentalis	Western minnow	50-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	90	15	dry	dry
Galaxias occidentalis	Western minnow	100+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	28	1	dry	dry
Galaxiella munda	Mud minnow	0-20	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Galaxiella munda	Mud minnow	20-50	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	19	dry	dry
Galaxiella munda	Mud minnow	50-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	1	dry	dry
Galaxiella munda	Mud minnow	100+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Nannoperca vittata	Western pygmy perch	0-20	n/a	n/a	dry	n/a	n/a	75	n/a	n/a	n/a	n/a	dry	dry	dry	9	1	dry	dry
Nannoperca vittata	Western pygmy perch	20-50	n/a	n/a	dry	n/a	n/a	211	n/a	n/a	n/a	n/a	dry	dry	dry	201	19	dry	dry
Nannoperca vittata	Western pygmy perch	50-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	2	0	dry	dry
Nannoperca vittata	Western pygmy perch	100+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Pseudogobius olorum	Swan river goby	0-20	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Pseudogobius olorum	Swan river goby	20-50	n/a	n/a	dry	n/a	n/a	6	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Pseudogobius olorum	Swan river goby	50-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Pseudogobius olorum	Swan river goby	100+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry

Native fish and crayfish species		Site code	MRAP1	MRAP2	MC02	MRAP8	MCLEOD	MC10	RRAP9	RRAP6	RRAP10	RUSHYCK	CHAP12	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Latin name	**Common name**	**Size class**																	
Afurcagobius suppositus	South-western goby	0-20	n/a	n/a	dry	n/a	n/a	2	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Afurcagobius suppositus	South-western goby	20-50	n/a	n/a	dry	n/a	n/a	73	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Afurcagobius suppositus	South-western goby	50-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Afurcagobius suppositus	South-western goby	100+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Bostockia porosa	Nightfish	0-20	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Bostockia porosa	Nightfish	20-50	n/a	n/a	dry	n/a	n/a	2	n/a	n/a	n/a	n/a	dry	dry	dry	1	7	dry	dry
Bostockia porosa	Nightfish	50-100	n/a	n/a	dry	n/a	n/a	1	n/a	n/a	n/a	n/a	dry	dry	dry	11	7	dry	dry
Bostockia porosa	Nightfish	100+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	8	0	dry	dry
Tandanus bostocki	Freshwater cobbler	0-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Tandanus bostocki	Freshwater cobbler	100-200	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Tandanus bostocki	Freshwater cobbler	200-400	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Tandanus bostocki	Freshwater cobbler	400+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Geotria australis	Pouched lamprey	0-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Geotria australis	Pouched lamprey	100-200	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	2	dry	dry
Geotria australis	Pouched lamprey	200-400	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Geotria australis	Pouched lamprey	400+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry

Native fish and crayfish species		Site code	MRAP1	MRAP2	MC02	MRAP8	MCLEOD	MC10	RRAP9	RRAP6	RRAP10	RUSHYCK	CHAP12	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Latin name	**Common name**	**Size class**																	
Leptatherina wallacei	Western hardyhead	0-20	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Leptatherina wallacei	Western hardyhead	20-50	n/a	n/a	dry	n/a	n/a	401	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Leptatherina wallacei	Western hardyhead	50-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Leptatherina wallacei	Western hardyhead	100+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax cainii	Smooth marron	0-20	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	1	dry	dry
Cherax cainii	Smooth marron	20-50	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	2	0	dry	dry
Cherax cainii	Smooth marron	50-76	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	2	0	dry	dry
Cherax cainii	Smooth marron	76-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	2	0	dry	dry
Cherax cainii	Smooth marron	100+	n/a	n/a	dry	n/a	n/a	1	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax quinquecarinatus	Gilgie	0-20	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	2	15	dry	dry
Cherax quinquecarinatus	Gilgie	20-50	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	1	1	dry	dry
Cherax quinquecarinatus	Gilgie	50-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax quinquecarinatus	Gilgie	100+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax crassimanus	Gilgie restricted	0-20	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax crassimanus	Gilgie restricted	20-50	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	3	0	dry	dry
Cherax crassimanus	Gilgie restricted	50-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax crassimanus	Gilgie restricted	100+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry

Native fish and crayfish species		Site code	MRAP1	MRAP2	MC02	MRAP8	MCLEOD	MC10	RRAP9	RRAP6	RRAP10	RUSHYCK	CHAP12	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Latin name	**Common name**	**Size class**																	
Cherax preissi	Koonac	0-20	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax preissi	Koonac	20-50	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax preissi	Koonac	50-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax preissi	Koonac	100+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Phalloceros caudimaculatus	One-spot live bearer	0-20	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Phalloceros caudimaculatus	One-spot live bearer	20-50	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Phalloceros caudimaculatus	One-spot live bearer	50-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Phalloceros caudimaculatus	One-spot live bearer	100+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Gambusia holbrooki	Gambusia	0-20	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Gambusia holbrooki	Gambusia	20-50	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Gambusia holbrooki	Gambusia	50-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Gambusia holbrooki	Gambusia	100+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax spp.	Yabby	0-20	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax spp.	Yabby	20-50	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax spp.	Yabby	50-100	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry
Cherax spp.	Yabby	100+	n/a	n/a	dry	n/a	n/a	0	n/a	n/a	n/a	n/a	dry	dry	dry	0	0	dry	dry

Appendix X — Macroinvertebrate data

Phylum / class / order / family	Taxon name (lowest identification possible)	MRAP1 *	MRAP2	MC02 *	MRAP8 *	MCLEOD *	MC10	RRAP9 *	RRAP6	RRAP10	RUSHYCK	CHAP12 *	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
NEMATODA (Phylum)		3				4						2						
NEMERTEA (Phylum)															1			
OLIGOCHAETA (Subclass)		45			4	52		38		4	9	91				1	6	2
TEMNOCEPHALIDA (Order)																		
Temnocephalida																		
Temnocephalidae	Temnocephala sp.				4													
TURBELLARIA (Class)																		
Tricladida																		
Dugesiidae	Turbellaria sp.											2						
ARACHNIDA (Class)																		
Acarina (Hydracarina)																		
Arrenuridae	Arrenurus sp.				4						2							
Pionidae	Gastropo.			4														
Hydryphantidae	Hydryphantidae spp.	35				4												
Limnesiidae	Limnesiidae spp.									1								
Oxidae	Oxus sp.				4													
Hygrobatidae	Coaustraliobates sp.				4													
Hygrobatidae	Hygrobatidae spp.							3										
Momoniidae	Momoniella sp.														1			
Unknown family	Hydracarina spp.	3						1		2								

Phylum / class / order / family	Taxon name (lowest identification possible)	MRAP1 *	MRAP2	MC02 *	MRAP8 *	MCLEOD *	MC10	RRAP9 *	RRAP6	RRAP10	RUSHYCK	CHAP12 *	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Acarina (Oribatida)																		
Unknown family	Oribatida spp.	45																
COLLEMBOLA (Subclass)																		
Poduromorpha																		
Hypogasturidae	Hypogastruridae spp.	3				4			2	1								
Symphypleona																		
Sminthurididae	Sminthurididae spp.														1			
CRUSTACEA (Subphylum)																		
Amphipoda																		
Chiltoniidae	Austrochiltonia sp.			360	149					2								
Chiltoniidae	Chiltoniidae spp.													1				
Perthiidae	Perthiidae spp.	83	27			20			38				14	11			6	7
Decapoda																		
Palaemonidae	*Palaemonetes australis*					4	14											
Parastacidae	*Cherax quinquecarinatus*								1					3		1		
Isopoda																		
Amphisopodidae	*Paramphisopus palustris*			12	4	24												
Corallanidae	*Tachaea caridophaga*						1											
GASTROPODA (Class)																		
Hygrophila																		
Ancylidae	Ferrissia sp.	10	2															
Lymnaeidae	*Pseudosuccinea columella*					4												
Planorbidae	Glyptophysa sp.								1			5						

Phylum / class / order / family	Taxon name (lowest identification possible)	MRAP1 *	MRAP2	MC02 *	MRAP8 *	MCLEOD *	MC10	RRAP9 *	RRAP6	RRAP10	RUSHYCK	CHAP12 *	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
	Glyptophysa concinna	19																
Unknown family	Gastropoda sp.		1															
INSECTA (Class)																		
Coleoptera																		
Hydrophilidae	Berosus sp. (larva)	10																
Dytiscidae	Limbodessus sp. (adult)						1											
	Allodessus bistrigatus (adult)	3																2
	Liodessus dispar (adult)										1	2						
	Liodessus sp. (adult)						1											
	Sternopriscus marginatus (adult)														2	10		
	Sternopriscus sp. (females)						1								3			
	Sternopriscus sp. (larva)						1	13	2						4		2	
	Necterosoma sp. (larva)								1									
	Platynectes sp. (larva)										4							
	Lancetes lanceolatus (adult)	3																
	Copelatus sp. (larvae)	6																
	Dytiscidae spp.							13							1	4		
Hydrophilidae	Paracymus sp. (larva)											2						
Scirtidae	Scirtidae spp.		3			4						7						
Diptera																		
Ceratopogonidae	Bezzia sp.												2				1	1
	Culicoides sp.					4												
	Nilobezzia sp		1			20												
Chironomidae (sub-family Chironominae)																		

Phylum / class / order / family	Taxon name (lowest identification possible)	MRAP1 *	MRAP2	MC02 *	MRAP8 *	MCLEOD *	MC10	RRAP9 *	RRAP6	RRAP10	RUSHYCK	CHAP12 *	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
	Stempellina sp.				16													
	Tanytarsus sp.	243	18	76	145	160	4	1050	74	8	24	10	6		3	1	6	
	Paratanytarsus sp.	6	7			36			53				3		1		18	
	Rheotanytarsus sp.														8			
	Harrissius sp.	3														1		
	Chironomus spp.	221	9	8		72		128	9	1		273		16	1		10	
	Dicrotendipes sp.	3	3									10						
	Polypedilum sp.		2	124	81	40			4	5		2		1		8	115	
	Paratendipes sp.					4												
	Cryptochironomus sp.	3									3	2						
	Microchironomus sp.					4												
	Chironominae spp.					32			1									
Chironomidae (sub-family Orthocladiinae)																		
	Corynoneura sp.	3			4	4		13										
	Thienemanniella sp.	13	6	12	30	216		128	10	4	2	12					3	
	Paralimnophyes sp. (dark sp.)					8						17						
	Cricotopus sp.	10	10	32	205	20	5	384	74		8		1			1		
	Orthocladiinae spp.		1			8												
Chironomidae (sub-family Tanypodinae)																		
	Tanypodinae sp.			4	21				32								3	
	Procladius sp.					4		243	3			2						
	Paramerina sp.		6	4		8			16			27	2	3	3	9		
Culicidae	Anopheles sp.													1				
Empididae	Empididae spp. (larvae)		1															

Phylum / class / order / family	Taxon name (lowest identification possible)	MRAP1 *	MRAP2	MC02 *	MRAP8 *	MCLEOD *	MC10	RRAP9 *	RRAP6	RRAP10	RUSHYCK	CHAP12 *	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Simuliidae	Austrosimulium sp.	10	4			228		26			42				3			
	Simulium ornatipes														1			
	Paracnephia sp.				9													
	Simuliidae spp.		5	4	13			179	5		13		1		5		1	2
Tipulidae	Tipulidae (MV sp10 and EWS sp5)		2															
	Tipulidae (EWS sp8)		1															2
	Tipulidae (MV sp45)																	1
	Tipulidae spp.			16	4	8				1								
Ephemoptera																		
Caenidae	*Tasmanocoenis tillyardi*			48		40		77			29				2			
Leptophlebiidae	Bibulmena kadjina	3	3	4		4			3			7	18		2	3	6	
	Genus S sp. AV1													4				
	Leptophlebiidae sp.			8		4			4			7	6		4	2		
Hemiptera																		
Corixidae	Corixidae spp.							51										
Veliidae	Microvelia sp.						1					10						1
Megaloptera																		
Corydalidae	Corydalidae spp.																1	
Odonata (sub-order Epiproctophora)																		
Aeshnidae	*Adversaeschna brevistyla*											2						
Hemicorduliidae	*Hemicordulia australiae*														1			
	Hemicordulia tau										2							
	Procordulia affinis															1		
	Hemicorduliidae spp.														2			

Phylum / class / order / family	Taxon name (lowest identification possible)	MRAP1 *	MRAP2	MC02 *	MRAP8 *	MCLEOD *	MC10	RRAP9 *	RRAP6	RRAP10	RUSHYCK	CHAP12 *	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
Synthemistidae	*Archaeosynthemis leachii*													1				
	Synthemistidae spp.					12						5						2
Telephlebiidae	Austroaeschna sp.										3				3			
	Telephlebiidae spp.												1					
	Epiproctophora spp.										1							
Odonata (sub-order Zygoptera)																		
Lestidae	*Austrolestes analis*	3																
Unknown family	*Zygoptera spp.*															2		
Plecoptera																		
Gripopterygidae	*Leptoperla australica*																	1
	Newmanoperla exigua		1			48												
	Riekoperla occidentalis				51													
	Gripopterygidae spp.				4				1							1	2	
Trichoptera																		
Hydroptilidae	Oxyethira sp				9													
	Hellyethira sp.	16					9	179	9						4			
	Hydroptilidae sp.											2					2	
Leptoceridae	*Lectrides parilis*					20												
	Notolina spira	3									10							
	Notalina sp.			48														
	Notoperata tenax					4							2					
	Notoperata sp. AV4					4												
	Notoperata sp.			4	4	4											2	
	Oecetis sp.										10							

Phylum / class / order / family	Taxon name (lowest identification possible)	MRAP1 *	MRAP2	MC02 *	MRAP8 *	MCLEOD *	MC10	RRAP9 *	RRAP6	RRAP10	RUSHYCK	CHAP12 *	CHAPX1	UCHAP1	UCHAPX2	UCHAP5	UCHAP6	FISHX3
	Triplectides AV1																	
	Triplectides neveipennis AV 21		1			4			2									6
	Leptoceridae sp.		60															
Philopotamidae	Hydrobiosella sp.																	1
Unknown family	Trichoptera sp.			20														

Notes:

** abundance was estimated from the sub-sample (see Section 3.4.6).*

spp. = several species are known, and that the identification cannot discriminate as to which species may be in the sample

sp. = only a single species is likely to be in the sample

EWS = The AWQC (Australian Water Quality Centre in SA Water) voucher coding system (SA Water was formerly the Engineering and Water Supply department)

MV = Museum of Victoria voucher coding system

AV = Australian Voucher coding system (national standard)

Nematoda, Nemertea, Oligochaeta and Temnocephalidea were not targeted for species identification

Unknown family indicated the animal could not be identified to species because it was juvenile or damaged

Appendix Y — Summary of key findings

Theme / Sub-theme	McLeod Creek	Rushy Creek	Chapman Brook	Upper Chapman Brook	Fisher Creek	Lower Blackwood River reach (between Chapman Brook and McLeod Creek)	Summary for study area
SWIRC ecological theme scores	Five themes assessed in six reach catchments	Five themes assessed in four reach catchments	Five themes assessed in two reach catchments	Five themes assessed in three reach catchments and four themes assessed in one reach catchment	Five themes assessed in one reach catchment	Four themes assessed in one reach catchment	Five themes assessed in 16 reach catchments and four themes assessed in two reach catchments
Largely unmodified	16	4	2	8	5	3	38
Slightly modified	11	9	7	6		1	34
Moderately modified	3	6	1	4			14
Substantially modified		1					1
Severely modified				1			1
Overall condition based on SWIRC ecological theme scores[i]	Generally in good condition: 27 of the 30 theme scores (90%) were in the top two condition bands (largely unmodified, slightly modified). The remaining three theme scores were in the third condition band (moderately modified).	Generally in good condition: 13 of 20* theme scores (65%) were in the top two condition bands (largely unmodified, slightly modified), however the proportion in the top two condition bands was lower than for other tributaries, suggesting that Rushy Creek was in slightly poorer condition comparatively. Of the remaining seven theme scores, six were in the third condition band (moderately modified) and one was in the fourth condition band (substantially modified).	Generally in good condition: nine of the 10 theme scores (90%) were in the top two condition bands (largely unmodified, slightly modified). The remaining theme score was in the third condition band (moderately modified).	Generally in good condition: 14 of the 19 theme scores (74%) were in the top two condition bands (largely unmodified, slightly modified). Of the remaining five theme scores, four were in the third condition band (moderately modified) and one was in the fifth condition band (severely modified).	Generally in good condition, all five theme scores (100%) were in the top condition band (largely unmodified).	Generally in good condition: all four theme scores (100%) were in the top two condition bands (largely unmodified, slightly modified).	Generally in good condition: 72 of the 88 theme scores (82%) were in the top two condition bands (largely unmodified, slightly modified). 14 theme scores were in the third condition band (moderately modified), one theme score was in the fourth condition band (substantially modified) and one theme score was in the fifth condition band (severely modified).

Theme / Sub-theme	McLeod Creek	Rushy Creek	Chapman Brook	Upper Chapman Brook	Fisher Creek	Lower Blackwood River reach (between Chapman Brook and McLeod Creek)	Summary for study area
Aquatic biota	Six sites assessed	Four sites assessed	Two sites assessed	Four sites assessed	One site assessed	No site assessed	17 reaches/sites assessed
Largely unmodified	2	1		1	1		5
Slightly modified	2	1	2	2			7
Moderately modified	2	2					4
Substantially modified							
Severely modified				1			1
Macroinvertebrates (site)	67 taxa were found within McLeod Creek; sites MCLEOD and MRAP1 had the highest taxa richness of all sites in the study (39 and 26 respectively). Total abundance per site ranged from 38 to 1168 individuals. In general, the macroinvertebrate community, was in good condition, with high taxa richness and several notable taxa: • two new larval forms of caddisfly larvae • two species of caddisfly larvae described as endangered (Sutcliffe 2003) • one species of stonefly larvae with a limited distribution within the south-west (WRM 2009) • one species of stonefly larvae with Gondwanic affinities (WRM 2009) • the freshwater mussel, *W. carteri*; this species is Priority 4 (DPaW 2013) • one species of introduced ribbed fluke snail. Chironomidae dominated total abundance at two sites (MRAP1 & MRAP8), which may suggest potential nutrient enrichment or increasing heavy metal concentration (Burton & Pitt 2002), or may have been influenced by warm water temperatures (Bunn et	37 taxa were found in Rushy Creek; taxa richness per site ranged from seven to 23. Total abundance per site ranged from 26 (RRAP10) to 2522 (RRAP9) individuals; this was the lowest and highest abundance found at a site in the study. One species of caddisfly larvae (*T. neveipennis* AV21) described as endangered (Sutcliffe 2003) was found at RRAP6. Chironomidae dominated total abundance at two sites (RRAP9 & RRAP6), which may suggest potential nutrient enrichment or increasing heavy metal concentration (Burton & Pitt 2002). At RRAP10 (southern tributary) the lowest taxa richness (seven) and abundance (26) may have been due to predatory pressure from the high abundance of fish (2000 *G. occidentalis)* found.	28 taxa were found in Chapman Brook; taxa richness per site was 10 and 21. Total abundance per site was 56 and 505 individuals. No species considered endangered (Sutcliffe 2003) or Threatened or Priority (DPaW 2013) were found. Chironomidae dominated total abundance at one site (CHAP12), which may suggest potential nutrient enrichment or increasing heavy metal concentration (Burton & Pitt 2002), or may have been influenced by warm water temperatures (Bunn et al. 1986). CHAP12 also had the highest abundance of Oligochaeta in the study; this group is capable of living in enriched systems with low oxygen and silty sediments (Gooderham & Tsyrlin 2002). CHAPX1 had the highest proportional abundance of EPT taxa of all the sites; these taxa are considered to be sensitive to changes in ecological health (e.g. Barbour et al. 1999).	37 taxa were found in Upper Chapman Brook; taxa richness per site ranged from nine to 16. Total abundance per site ranged from 47 to 184 individuals. A new larval form of Notoperata (caddisfly larvae) was at site UCHAP6. The freshwater mussel, *W. carteri*; this species is Priority 4 (DPaW 2013). UCHAP1 had low taxa richness and abundance compared with other study sites, likely due to the sample being collected from a disconnected pool. Chironomidae dominated total abundance at one site (UCHAP6), which may suggest potential nutrient enrichment or increasing heavy metal concentration (Burton & Pitt 2002), or may have been influenced by warm water temperatures (Bunn et al. 1986).	12 taxa and 28 individuals were found in Fisher Creek. One species of caddisfly larvae described as endangered (Sutcliffe 2003) was found. The site was dominated by shredders which tend to be more sensitive to pollution than the more generalist collectors (WRM 2009).	Sites not sampled for biota.	**Value** 102 distinct taxa were found in the study area; taxa richness per site ranged from seven to 39. Total abundance per site ranged from 26 to 2522 individuals. Notable taxa included: • two new larval forms of caddisfly larvae were found across fours in the study (McLeod Creek and Upper Chapman Brook) • two species of caddisfly larvae described as endangered (Sutcliffe 2003) were found across four sites (in McLeod, Rushy and Fisher creeks) • one species of stonefly larvae with a limited distribution within the south-west (WRM 2009) was found at one site in McLeod Creek • one species of stonefly larvae with Gondwanic affinities (WRM 2009) was found at two sites in McLeod Creek • one species of freshwater mussel was observed at four sites (McLeod Creek and Upper Chapman Brook); listed as Priority 4 (DPaW 2013). **Potential threat** One species of introduced ribbed fluke snail was found in McLeod Creek. Chironomidae dominated total abundance at six sites (across all systems except Fisher Creek), which

Theme / Sub-theme	McLeod Creek	Rushy Creek	Chapman Brook	Upper Chapman Brook	Fisher Creek	Lower Blackwood River reach (between Chapman Brook and McLeod Creek)	Summary for study area
	al. 1986). The taxa richness and abundance at MC10 was lower than other sites, most likely due to the site varying from fresh to moderately saline during the year.						may suggest potential nutrient enrichment or increasing heavy metal concentration (Burton & Pitt 2002), or influence from warm water temperatures (Bunn et al. 1986).
Fish and crayfish **(site)**	11 native fish and crayfish species were found in the system – highest richness of tributaries studied. Nine native species found at MCLEOD and seven at MC10 – high richness for sites in south-west river systems[ii]. Species included *G. munda* (Threatened species) at four sites. It was the only tributary were the following were found: *L. wallacei, A. suppositus* (both have marine affinities) and *T. bostocki.* Exotic species only found at two of six sites. 71 exotic fish were found at MC02 in Feb 2013 – highest abundance of exotics found at a site. *P caudimaculatus* was only found at one site in the study (MC02). Lower sites appeared to be significant nursery, supporting juveniles of six species. Individuals from six species appeared to be gravid, suggesting the creek is a possible spawning habitat. Increased abundance in the lower catchment site in Feb 2013 suggests area used as a permanent water refuge.	Seven native fish and crayfish species were found in the system. Six native species found at RUSHYCK (below dam) – high richness for sites in south-west river systems[ii]. Species richness was marginally lower at remaining, although all species present below the dam were detected at sites above the dam. Exotic species were found at two sites, in low abundance (max. 10 individuals in a sample). High abundance (2000 individuals) of *G. occidentalis* found in Oct 2012, which may suggest congregation for spawning. Successful recruitment (juveniles) evident for a number of species. The large dam at the lower end of Rushy Creek may provide a permanent water refuge for species; other refugia may exist further upstream in the catchment.	Six native fish and crayfish species were found in the system. All six species were found in the lower site (CHAPX1); high richness for sites in south-west river systems[ii]. Species richness was lower at the top of catchment site (two species, CHAP12). The richness and distribution may reflect permanency of water; both sites were dry in Feb 2012. One individual of one exotic species was found (*G. holbrooki*). No juveniles were found, suggesting nursery areas are located elsewhere.	Eight native fish and crayfish species were found in the system. Seven native species were found at UCHAP5 – high richness for sites in south-west river systems[ii]. Species included *G. munda* (Threatened species) at UCHAP5 in Oct 2012 and Feb 2013, and *G. australis* (Priority 1 species) at UCHAP5 in Feb 2013. This was the only occurrence of *G. australis* in the study, the presence of which has previously only been noted as anecdotal evidence. Two exotic species were found in low abundance (max. three individuals in a sample). Juveniles were found at two sites in Feb 2013, suggesting these areas may be an important nursery for several species. Abundance at one site more than doubled in Feb 2013 compared with Oct 2012, suggesting a potential permanent water refuge. Gravid individuals were observed at three sites suggesting a likely spawning ground for some species.	Four native fish and crayfish species were found in the system. Species included *G. munda* (Threatened species), and *C. preissii;* this was the only occurrence of *C. preissii* in the study. No exotic species were found. The observed richness is expected given the likelihood of the system drying and containing natural barriers to movement (site was dry in Feb 2012, shallow in nature with considerable woody debris). The site was a nursery for *G. munda* and *C. crassimanus.* It was the only site where *juvenile G. munda* were recorded, including post-larvae sized individuals suggesting recent spawning.	Sites not sampled for biota.	**Value** 13 native fish and crayfish species were found in the study area, 11 of which are endemic to south-west Western Australia. High native species richness (≥6 species[ii]) found in 10 of 19 samples. *G. munda* (Threatened species) was found in three systems (McLeod and Fisher creeks and Upper Chapman Brook). *G. australis* (Priority 1 species) was found in one system (Upper Chapman Brook). Exotic species were absent from over half the sites (nine of 16 sites). Of the sites where exotics were found, the abundance was ≤10 individuals with the exception of MC02 (70 individuals). Juvenile species were present in McLeod and Rushy creeks, Upper Chapman Brook and Fisher Creek, suggesting the presence of nursery areas in these systems. Evidence of spawning was noted in McLeod Creek, Upper Chapman Brook and Fisher Creek. **Potential threat** Generally species richness was lower in the upper catchment sites of all systems, most likely due to drying in the upper catchments; the drying and species richness may be a natural occurrence or may be exacerbated by climate change.

Theme / Sub-theme	McLeod Creek	Rushy Creek	Chapman Brook	Upper Chapman Brook	Fisher Creek	Lower Blackwood River reach (between Chapman Brook and McLeod Creek)	Summary for study area
Water quality index scores	Six reaches/sites assessed	Four reaches/sites assessed	Two reaches/sites assessed	Three reaches/sites assessed	One reach/site assessed	One reach/site assessed	17 reaches/sites assessed
Largely unmodified	5	3	2	3	1	1	15
Slightly modified	1	1					2
Moderately modified							
Substantially modified							
Severely modified							
Number of sites where grab and in situ samples were taken.	*Jun 2012: 2* *Oct 2012: 6* *Feb 2013: 1*	*Jun 2012: 0* *Oct 2012: 4* *Feb 2013: 0*	*Jun 2012: 2* *Oct 2012: 2* *Feb 2013: 0*	*Jun 2012: 3* *Oct 2012: 3* *Feb 2013: 2*	*Jun 2012: 1* *Oct 2012: 1* *Feb 2013: 0*	*Jun 2012: 2* *Oct 2012: 2* *Feb 2013: 3*	*Jun 2012: 10* *Oct 2012: 18* *Feb 2013: 6*
	Note: excludes diel dissolved oxygen, temperature and non-nutrient contaminants – see notes for these parameters.						
Nitrogen **(site)** *Guideline: total nitrogen default guideline trigger value for slightly disturbed lowland river ecosystems in south-west Australia of 1.2 mg/L (ANZECC & ARMCANZ 2000a).*	Total nitrogen was below the guideline in six of nine samples. The guideline was exceeded in three samples, with a max. concentration of 3.3 mg/L.	Total nitrogen was below the guideline in all samples.	Total nitrogen was below the guideline in three of four samples. The guideline was exceeded in one sample, with a max. concentration of 1.9 mg/L.	Total nitrogen was below the guideline in five of eight samples. The guideline was exceeded in three samples, with a max. concentration of 4.1 mg/L.	Total nitrogen was below the guideline in all samples.	Total nitrogen was below the guideline in all samples taken in the main channel. The guideline was exceeded in one sample taken in the tributary, concentration 3.3 mg/L.	**Value** Total nitrogen was below the guideline in all samples taken Rushy and Fisher creeks, and the main channel of the lower Blackwood River reach. Total nitrogen was below the guideline in most samples taken in McLeod Creek and Upper Chapman Brook. **Potential threat** Total nitrogen exceeded the guideline in eight of 34 samples.
Phosphorus **(site)** *Guideline: total phosphorus default guideline trigger value for slightly disturbed lowland river ecosystems in south-west Australia of 0.065 mg/L (ANZECC & ARMCANZ 2000a).*	Total phosphorus was below the guideline in all samples.	Total phosphorus was below the guideline in all samples.	Total phosphorus was below the guideline in all samples.	Total phosphorus was below the guideline in all samples.	Total phosphorus was below the guideline in all samples.	Total phosphorus was below the guideline in all samples.	**Value** Total phosphorus was below the guideline in all samples.
Turbidity **(site)** *Turbidity default guideline*	Turbidity was below the guideline in all samples.	Turbidity was below the guideline in three of four samples. The guideline was exceeded in one	Turbidity was below the guideline in all samples.	Turbidity was below the guideline in seven of eight samples. The guideline was exceeded in one sample, with	Turbidity was below the guideline in all samples.	Turbidity was below the guideline in all samples.	**Value** Turbidity was below the guideline in all samples taken in McLeod Creek, Chapman Brook, Fisher Creek and

Theme / Sub-theme	McLeod Creek	Rushy Creek	Chapman Brook	Upper Chapman Brook	Fisher Creek	Lower Blackwood River reach (between Chapman Brook and McLeod Creek)	Summary for study area
trigger value for slightly disturbed lowland and upland river ecosystems in south-west Australia of 10 – 20 NTU (ANZECC & ARMCANZ 2000a).		sample, with a concentration of 27 NTU.		a concentration of 30 NTU.			the lower Blackwood River reach. Turbidity was below the guideline in most samples taken in Rushy Creek and Upper Chapman Brook, with one sample exceeding the guideline in each river system.
Diel dissolved oxygen (site) *Dissolved oxygen guideline based on biotic tolerance: below 5 mg/L may be stressful to many freshwater fish species (Koehn & O'Connor 1990).* *Note: Diel dissolved oxygen was only sampled in Oct 2012 and Feb 2013.*	Dissolved oxygen was above the guideline in six of seven samples. Dissolved oxygen was below the guideline in one sample (MRAP1, below 5 mg/L for 12 hours).	Diel dissolved oxygen was above the guideline in all four samples.	Dissolved oxygen was above the guideline in one of two samples. Dissolved oxygen was below the guideline in one sample (CHAPX1, below 5 mg/L for two hours).	Diel dissolved oxygen above the guideline in four of five samples. Dissolved oxygen was below the guideline in one sample (UCHAPX2, below 5 mg/L for 22 hours).	Diel dissolved oxygen was above the guideline in all samples.	Diel dissolved oxygen not measured.	**Value** Diel dissolved oxygen was above the guideline in all samples taken in Rushy and Fisher creeks. Diel dissolved oxygen was above the guideline in most samples taken in McLeod Creek and Upper Chapman Brook, and most of the time in the samples taken in Chapman Brook. **Potential threat** Diel dissolved oxygen was below the guideline for a substantial time in two samples (MRAP1 and UCHAPX2).
Diel temperature (site) *Diurnal fluctuation guideline based on biotic tolerance: <4°C is an indicative threshold for healthy ecosystem function (Storer et al. 2011b).* *Note: Diel temperature was only sampled in Oct 2012 and Feb 2013.*	The diel temperature range was below the guideline in five of seven samples. The range slightly exceeded the guideline in one sample (MRAP8, 6.4 °C) and substantially exceeded the guideline in one sample (MRAP1, 13°C).	The diel temperature range was below the guideline in two of four samples. The range slightly exceeded the guideline in two samples (RRAP9 5°C and RUSHYCK, 4.6°C).	The diel temperature range was below the guideline in one of two samples. The range slightly exceeded the guideline in one sample (CHAP12, 4.5 °C).	The diel temperature range was below the guideline all five samples.	The diel temperature range slightly exceeded the guideline in one sample (FISHX3 4.9°C).	Diel temperature was not measured.	**Value** The diel temperature range was below the guideline all samples taken in Upper Chapman Brook. The range was below the guideline, or only slightly exceeded the guideline at most sites in McLeod Creek and all sites in Rushy Creek, Chapman Brook and Fisher Creek. **Potential threat** The diel temperature range substantially exceeded the guideline in one sample in McLeod Creek.
Electrical conductivity (salinity) **(reach & site)**	Estimated salinity was categorised as fresh (<500 mg/L TDS) and was below the guideline for all samples except for site MC10 in February 2013 which was moderately saline (3760 mg/L TDS), most likely due to tidal movement of estuarine water from the Blackwood River.	Estimated salinity was categorised as fresh (<500 mg/L TDS) and was below the guideline for all samples.	Estimated salinity was categorised as fresh (<500 mg/L TDS) and was below the guideline for all samples.	Estimated salinity was categorised as fresh (<500 mg/L TDS) and was below the guideline for all samples.	Estimated salinity was categorised as marginal (847 mg/L TDS) in June 2012 and fresh (483 mg/L TDS) in October 2012. On both occasions the salinity was below the guideline.	At sites on the Blackwood River estimated salinity was categorised as moderately saline (2000-5000 mg/L TDS) and was above the guideline for all samples, most likely due to tidal movement of estuarine water. Site BLA16X on a tributary was fresh (226 mg/L	**Value** Estimated salinity was below the guideline for all samples with the exception of sites MC10 in February 2013 and sites on the Blackwood River – most likely due to tidal movement of estuarine water in the Blackwood River.

Theme / Sub-theme	McLeod Creek	Rushy Creek	Chapman Brook	Upper Chapman Brook	Fisher Creek	Lower Blackwood River reach (between Chapman Brook and McLeod Creek)	Summary for study area
						TDS) and below the guideline in February 2013.	**Potential threat** Further sampling is required to determine the spatial and temporal extent of saltwater intrusion into McLeod Creek.
Non-nutrient contaminants **(site)** *Interim sediment quality guidelines (ISQGs) applied (ANZECC & ARMCANZ 2000a).*			One site assessed	Three sites assessed			
	No samples taken.	No samples taken.	Of the pesticides and herbicides assessed, concentrations above the laboratory limits of reporting were not recorded[iii]. Metals detected in the sediment were all at concentrations below available guidelines.	Of the pesticides and herbicides assessed, concentrations above the laboratory limits of reporting were not recorded[iii]. Metals detected in the sediment were all at concentrations below available guidelines.	No samples taken.	No samples taken.	**Values** Of the pesticides and herbicides assessed, concentrations above the laboratory limits of reporting were not recorded[iii]. Metals detected in the sediment were all at concentrations below available guidelines.

Theme / Sub-theme	McLeod Creek	Rushy Creek	Chapman Brook	Upper Chapman Brook	Fisher Creek	Lower Blackwood River reach (between Chapman Brook and McLeod Creek)	Summary for study area
Physical form index scores	Six reaches/sites assessed	Four reaches/sites assessed	Two reaches/sites assessed:	Four reaches/sites assessed	One reach/site assessed	One reach/site assessed:	18 reaches assessed:
Largely unmodified	3				1		4
Slightly modified	3	2	2	2		1	10
Moderately modified		2		2			4
Substantially modified							
Severely modified							
Erosion							
(site) *Definitions of vegetation layer cover and height:* • *dense 50–100%* • *moderate 10–50%* • *sparse 1–10%* • *short trees <10 m* • *tall trees >10 m.*	Extent of erosion low at all six sites (0–20 % of site length). Cover of vegetation in the streamside zone (proxy for bank stabilisation) varied between vegetation layers and sites: • the upper (MRAP1, MRAP2) and mid catchment (MC02) had a combination of dense to moderate cover, suggesting a degree of protection from future erosion • southern tributary (MRAP8) and lower catchment (MCLEOD and MC10) sites had a dense cover of shrubs, but sparse or absent cover of short trees and an absent tall tree layer, suggesting potential vulnerability to future erosion.	Extent of erosion low at one site (0–5 % of site length), mid-range at one site (21–50%) and high at one site (50–100%). Cover of vegetation in the streamside zone (proxy for bank stabilisation) varied between sites: • the southern tributary site (RRAP10) had two dense layers and one absent layer, suggesting a degree of protection from future erosion • the main channel (RRAP6) had one moderate, one sparse and one absent layer, suggesting potential vulnerability to future erosion • the lower catchment site (RUSHYCK) had one dense, one sparse and one absent layer, suggesting potential vulnerability to future erosion • the northern tributary site (RRAP9) had two sparse layers and one absent layer, suggesting potential vulnerability to future erosion.	Extent of erosion low at all both sites (0–5 % of site length). Both sites had a dense cover of shrubs, one sparse and one moderate tree layer, suggesting a degree of protection from future erosion.	Extent of erosion low at two sites (0–5 % of site length), and high at two sites (50–100%). Cover of vegetation in the streamside zone (proxy for bank stabilisation) varied between sites: • the upper (UCHAP1) and northern tributary (UCHAPX2) sites had one dense and two moderate layers, suggesting a degree of protection from future erosion. • the mid catchment sites (UCHAP5 and UCHAP6) had two dense layers and one moderate layer, suggesting a degree of protection from future erosion.	Extent of erosion low at the site (0–5 % of site length). The site had two dense layers and a moderate layer, suggesting a degree of protection from future erosion.	Extent of erosion low at the site (0–5 % of site length). The site had two dense layers and sparse layer, suggesting a degree of protection from future erosion.	**Value** Extent of erosion low at 13 of 18 sites (0–20 % of site length). Cover of vegetation in the streamside zone (proxy for bank stabilisation) was moderate to dense at 12 of 18 sites, suggesting a degree of protection from future erosion. **Potential threat** Extent of erosion moderate to high at all five of 18 sites (21–100 % of site length). Cover of vegetation in the streamside zone (proxy for bank stabilisation) was moderate to sparse or absent, suggesting potential vulnerability to future erosion.
Longitudinal connectivity **(reach)**	No major dams or gauging stations influencing[iv] the reaches. Potential minor dams which may influence biota passage	No major dams or gauging stations influencing the reaches. Potential minor dams which may influence biota passage	No major dams influencing the reaches. Potential minor dams which may influence biota passage into and along both reaches.	No major dams influencing the reaches. Potential minor dams which may influence biota passage into and along all four reaches.	No major dams, minor dams or gauging stations influencing the reach. Road/rail crossing density 0.4 per km.	No major dams or road/rail crossings influencing the reach. Potential minor dam and gauging station which may	**Value** No major dams influencing the study reaches. Low road/rail crossing density

Theme / Sub-theme	McLeod Creek	Rushy Creek	Chapman Brook	Upper Chapman Brook	Fisher Creek	Lower Blackwood River reach (between Chapman Brook and McLeod Creek)	Summary for study area
	into and along three of six reaches. Road/rail crossing density ranges from 0 per km to 1.6 per km.	into and along all four reaches. Road/rail crossing density ranges from 0.5 per km to 1.0 per km.	Road/rail crossing density ranges from 0.7 per km to 1.1 per km.	Road/rail crossing density ranges from 0.4 per km to 0.8 per km.		influence biota passage into and along the reach.	(max. 1.6 per km). **Potential threat** Potential minor dams may influence biota passage into and along most reaches (14 of 18). Potential gauging stations may influence biota passage into and along seven reaches.
Artificial channel **(reach)**	No occurrences of artificial channel[v] in catchment.	No occurrences of artificial channel in catchment.	No occurrences of artificial channel in catchment.	No occurrences of artificial channel in catchment.	No occurrences of artificial channel in catchment.	No occurrences of artificial channel in catchment.	**Value** No occurrences of artificial channel in catchment.

Theme / Sub-theme	McLeod Creek	Rushy Creek	Chapman Brook	Upper Chapman Brook	Fisher Creek	Lower Blackwood River reach (between Chapman Brook and McLeod Creek)	Summary for study area
Fringing zone index scores	Six reaches/sites assessed	Four reaches/sites assessed	Two reaches/sites assessed	Four reaches/sites assessed	One reach/site assessed	One reach/site assessed	18 reaches/sites assessed
Largely unmodified	3			1	1	1	6
Slightly modified	2	1	1	1			5
Moderately modified	1	2	1	2			6
Substantially modified		1					1
Severely modified							
Extent of fringing zone **(reach)**	High extent of fringing zone vegetation along five of the six reaches (>70% length vegetated; average width >30 m). Low extent along one reach (MRAP1) in upper catchment: 29% length vegetated and average width 11 m.	Variable extent across reaches. Highest on the northern tributary (72% length, average width 30 m) and main channel (59% length, 20 m average width). Lower on the southern tributary (32% length, average width 14 m). Lowest extent of study reaches on lower catchment (17% length, average width 6 m).	Similar extent on both reaches, about 50% length and average width 22 m. Lower than the mean for study reaches.	Variable extent across reaches. Highest in upper catchment (UCHAP1, 100% length, average width 50 m or greater). Also high in mid catchment downstream of tributary confluence (UCHAP6, 74% length, average width 28 m). Lower extent in northern tributary (UCHAPX2, 62% length, average width 20 m). Lowest extent in mid catchment upstream of tributary confluence (UCHAP5, 24% length, average width 13 m).	High extent of fringing zone vegetation (>100% length vegetated; average width 50 m or greater).	High extent of fringing zone vegetation (73% length vegetated; average width 32 m).	Variable extent across study reaches. Mean extent: 65% (± 25%) length, average width 28 m (± 13 m). **Value** Maximum extent 100% length; average width 50 m or greater. **Potential threat:** Minimum extent 17% length and average width 6 m. Due to dam, revise method to match FARWH/SWIRC.
Nativeness **(site)**	Proportion of exotic species in ground cover layer varied between sites: • highest in the top site of the upper catchment (MRAP1, 50–75%) • mid-range in the southern tributary (MRAP8, 10–50%) • low or absent in the upper and mid catchment sites (MRAP2, MC02) and the lower catchment (MCLEOD, MC10). Proportion of exotic species in shrub layer low or absent (0% at four sites, 1–10% at two sites). No exotic tree species identified.	High proportion of exotic species in ground cover layer found at two sites (upper catchment RRAP9 and lower catchment RUSHYCK, 75–100%). Mid-range proportion found at site in main channel (RRAP6, 10–75%), low proportion found at site in southern tributary (RRAP10, 0–10%). Proportion of exotic species in shrub layer low or absent (0% at two sites, 1–10% at two sites). No exotic tree species identified.	Exotic species absent from the lower catchment site (CHAP1). At the upper catchment site (CHAP12), proportion of exotic species in the ground cover layer as low (1–10%); proportion in the shrub layer was slightly higher (10–50%). No exotic tree species identified.	High proportion of exotic species in ground cover layer found at site in the northern tributary (UCHAPX2, 75–100%) and mid catchment downstream of tributary confluence (UCHAP6, 50–100%). Lower proportion found at site in the mid catchment upstream of tributary confluence (UCHAP5, 50–75%). Low proportion found at the site in the upper catchment (UCHAP1, 0–10%). Proportion of exotic species in shrub layer low or absent (0% at three sites, 1–10% at one site). No exotic tree species identified.	No exotic species in any vegetation layer.	No exotic species in any vegetation layer.	**Value** Exotic species absent in all vegetation layers at four sites (MC10, CHAX1, FISHX3, BLA15/16). No exotic tree species identified in study. Exotic species absent from shrub layer at 12 sites, and low at remaining sites (1–10% at five sites, 10–50% at one site). Exotic species absent from ground cover layer at four sites, proportion low (1–10%) at six sites, and mid-range (10–50%) at one site. **Threat** Proportion of exotic species in the ground cover layer was high (50–100%) at seven sites.

Theme / Sub-theme	McLeod Creek	Rushy Creek	Chapman Brook	Upper Chapman Brook	Fisher Creek	Lower Blackwood River reach (between Chapman Brook and McLeod Creek)	Summary for study area
Hydrological change			One catchment assessed				
Largely unmodified							
Slightly modified			1				
Moderately modified							
Substantially modified							
Severely modified							
Supplementary information	Two potential permanent water refugia identified in February 2013 via limited ad-hoc observations: excavation/soak downstream of site MRAP2, and the lower reaches of the McLeod Creek.	One potential permanent-water refugia identified in February 2013 via limited ad-hoc observations: large farm dam in the lower Rushy Creek.	Two potential permanent water refugia identified in February 2013 via limited ad-hoc observations: UCHAPX2 and UCHAP5	One potential permanent-water refugia identified in February 2013 via limited ad-hoc observations: Chapman Pool at the confluence with the Blackwood River.	Sites FISHX3 dry in February 2013. No other locations visited.	Sites BLA15, BLA16 and BLA16X were flowing in February 2013. No other locations visited.	Several potential permanent water refugia were identified. Comprehensive sampling required to determine spatial and temporal distribution of refugia.
Flow stress ranking sub-theme	Not assessed	Not assessed	Flow stress ranking score of 0.7 for Chapman Brook. Chapman Brook receives higher flows than the reference system, which may indicate the possibility of increased impacts during the high flow period, such as increased erosion and altered flow cues for biota at various lifecycle stages (e.g. spawning).	Not assessed	Not assessed	Not assessed	

Theme / Sub-theme	McLeod Creek	Rushy Creek	Chapman Brook	Upper Chapman Brook	Fisher Creek	Lower Blackwood River reach (between Chapman Brook and McLeod Creek)	Summary for study area
Catchment disturbance index scores	Six reach catchments assessed	Four reach catchments assessed	Two reach catchments assessed	Four reach catchments assessed	One reach catchment assessed	One reach catchment assessed	18 reach catchments assessed
Largely unmodified	3			3	1	1	8
Slightly modified	3	3	2	1			10
Moderately modified							
Substantially modified							
Severely modified							
Land use (subcatchment)	Catchment dominated by conservation/minimal use (63% area); grazing 29%, plantation forestry 6%, urban/transport/mining 2%, intensive/irrigated agriculture 1%.	Low proportion of conservation/minimal use (25% area) compared with other study catchments. High proportion of intensive/irrigated agriculture uses (12%). Grazing 54%, plantation forestry 8%, urban/mining/transport 2%.	Almost equal proportion of conservation/minimal use (46% area) and grazing (43%). Intensive/irrigated agriculture 7%, urban/mining/transport 2%, plantation forestry 1%.	Catchment dominated by conservation/minimal use (61% area). Grazing 29%, intensive/irrigated agriculture 7%, urban/mining/transport 2%, plantation forestry 1%. Only catchment with dryland cropping use (0.1%).	Catchment dominated by conservation/minimal use (99% area); urban/mining/transport covered 1%.	Catchment dominated by grazing (55% area) and conservation/minimal use (43% area). Intensive/irrigated agriculture 1%, urban/mining/transport 1%, plantation forestry 1%.	**Value** Dominance of conservation/minimal use in McLeod Creek, Upper Chapman Brook and Fisher Creek. Low proportion of reach catchment areas covered by intensive/irrigated agriculture and urban/mining/transport (which have the highest ranking for impact on river health, Storer et al. 2011b).
Infrastructure (subcatchment)	Proportion of each reach catchment covered by infrastructure was minimal (max. 1.6%).	Proportion of each reach catchment covered by infrastructure was minimal (max. 1.6%).	Proportion of each reach catchment covered by infrastructure was minimal (max. 1.3%).	Proportion of each reach catchment covered by infrastructure was minimal (max. 1.1%).	Proportion of each reach catchment covered by infrastructure was minimal (max. 0.7%).	Proportion of each reach catchment covered by infrastructure was minimal (max. 0.8%).	**Value** Proportion of each reach catchment covered by infrastructure was minimal (max. 1.6%).
Land cover change (subcatchment)	Minimal increase in vegetation cover 2007 to 2011 in one subcatchment (MC02, 1.1% area). Minimal decrease in five subcatchments (max. 11.4%, MRAP8).	Minimal increase in vegetation cover 2007 to 2011 in two subcatchments (max 2.9% area). Minimal decrease in two subcatchments (max. 0.5%).	Minimal decrease in vegetation cover 2007 to 2011 in both subcatchments (1.1% area in each).	Minimal increase in vegetation cover 2007 to 2011 in all subcatchments (max 0.6% area).	No change in vegetation cover 2007 to 2011.	Minimal decrease in vegetation cover 2007 to 2011 (0.6% of area).	**Value** Minimal decrease in vegetation cover 2007–2011 in 10 reach catchments (max. 11.4% area); no change or increase in vegetation cover in 8 reach catchments.

[i] *Based on SWIRC scores, calculated from field data collected during the October 2012 sampling event, and desktop data collected in 2012.*

[ii] *It is rare to find more than six native fish and crayfish species at any one site in south-west river systems (Storer et al. 2011b).*

[iii] *Caution should be taken when interpreting these results as many of the available guidelines are set at concentrations lower than current analytical methods are able to achieve.*

[iv] *On the reach or within 40 km of the start or end of the reach.*

[v] *As mapped at 1:250,000 scale.*

Appendix Z — Map disclaimer and data acknowledgements

The maps in this publication were produced by the Department of Water with the intent that they be used as illustrations in this report. While the department has made all reasonable efforts to ensure the accuracy of this data, it accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

The Department of Water acknowledges the following datasets and their custodians in the analysis of data and production of the maps:

Dataset name	**Custodian acronym**	**Metadata year**
1 second SRTM derived digital elevation model (DEM) v1.0	GA	2009
1:500 000 Interpreted bedrock geology of Western Australia 2001	DMP	2002
Aerial photo: Busselton western extension 2012 50 cm	Landgate	2012
Aerial photo: Leeuwin 2012 50 cm	Landgate	2012
Blackwood Basin land use 2005 – 2007	DoW	2012
Coastline, Western Australian	DoW	2006
DPaW tracks and trails	DPaW	2012
Farm dams	DoW	2008
Hydrography linear	DoW	2006
Hydrography linear (hierarchy)	DoW	2007
Hydrography theme from GEODATA TOPO 250K Series 3	GA	2006
Hydrographic subcatchments	DoW	2013
Land Monitor vegetation mask (south region) 2007	Landgate	2007
Land Monitor vegetation mask (south region) 2011	Landgate	2011
Native vegetation current extent dataset	DAFWA	2011
Petroleum pipelines, Western Australian	DMP	2005
Pre-European vegetation	DAFWA	2002
Railways	Landgate	2012
Road centrelines	Landgate	2014
Soil-landscape systems (version 5) extracted 10/9/2012	DAFWA	2012
Soil-landscape zone (version 5) extracted 6/12/2012	DAFWA	2012
Statewide topographic contours	Landgate	2009
Stream barrier geodatabase	DoW	In prep
Stream salinity status (Mayer et al. 2005)	DoW	2005
Surface geology – adapted from Baddock et al. (in prep.)	-	-
Surface water allocation area	DoW	2013
Towns, Western Australian	Landgate	2013
Water information network (WIN) sites	DoW	2006

The maps have been produced using the following data and projection information:

Vertical Datum: AHD (Australian Height Datum)

Horizontal Datum: GDA 94 (Geocentric Datum of Australia 1994)

Projection System: Map Grid of Australia (MGA) 1994 Zone 50

Original ArcMap documents (*.mxd):
J:\gisprojects\Project\330\30000_39999\33032003\007_report

Shortened forms

AB	aquatic biota
AHD	Australian height datum
ANZECC	Australian and New Zealand Environment and Conservation Council
APHA	American Public Health Association
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AUSRIVAS	Australian River Assessment Scheme
BoM	Bureau of Meteorology
CD	catchment disturbance
CENRM	Centre of Excellence in Natural Resource Management
CFOC	Caring for Our Country
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CV	coefficient of variation
D Org N	Dissolved organic nitrogen
DEM	Digital elevation model
DNA	Deoxyribonucleic acid – context of this study, identification of macroinvertebrate species
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DoW	Department of Water
DPaW	Department of Parks and Wildlife (formerly Department of Environment and Conservation)
EPA	Environmental Protection Authority
EPT taxa	Ephemeroptera: mayflies; Plecoptera: stoneflies; Trichoptera: caddisflies
ESRI	Environmental Systems Research Institute

FARWH	Framework for the Assessment of River and Wetland Health
FSR	flow stress ranking
FZ	fringing zone
GA	Geoscience Australia
GIS	Geographical information systems
HC(I)	hydrological change (index)
HEVAE	high ecological value aquatic ecosystem
HF	high flow
IOCI	Indian Ocean Climate Initiative
ISQG	interim sediment quality guideline
ITFM	Intergovernmental Task Force on Monitoring
IUCN	International Union for Conservation of Nature and Natural Resources
LF	low flow
N as NH_3/NH_4	Nitrogen as ammonia/ammonium
N0x [NO_2+NO_3]	total oxidised nitrogen (sum of nitrite (NO_2) and nitrate (NO_3))
NATA	National Association of Testing Authorities
NDVI	normalised difference vegetation index
NMI	National Measurement Institute
NTU	nephelometric turbidity units
NWC	National Water Commission
PF	physical form
PZ	proportion of zero flow
RAP	river action plan
SKM	Sinclair Knight Mertz

SP	seasonal period
SRP	Soluble reactive phosphorus
SWCC	South West Catchments Council
SWIRC	South West Index of River Condition
TDS	total dissolved solids
TKN	total kjeldahl nitrogen
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
WQIP	water quality improvement plan
WRC	Waters and Rivers Commission
WRM	Wetland Research & Management
WSQ	water and sediment quality

Glossary

Abstraction	The permanent or temporary withdrawal of water from any source of supply, so that it is no longer part of the resources of the locality.
Ammocetes	Larval stage of a lamprey
Baseline data	Data representing the existing elements, characteristics and trends in an area to provide a measure against which change can be assessed.
Berried	Bearing eggs
Bio-connectivity	System connectivity as it relates to passage of fish and other aquatic fauna
Biota	Living things e.g. flora and fauna.
Confluence	Running together, flowing together; such as where a tributary joins a river.
Diel	Relating to 24 hour period.
Dissolved oxygen	The concentration of oxygen dissolved in water or effluent, measured in milligrams per litre (mg/L) or % saturation.
Diurnal cycle	A pattern that recurs every 24 hours.
Ecological health	The extent to which ecological processes and functions are resilient and adaptive, giving rise to self-regulation, stability and diversity in populations and ecosystems.
Ecological values (of a waterway)	The natural ecological processes occurring within water-dependent ecosystems and the biodiversity of these systems.
Ecological water requirements	The water regime needed to maintain the ecological values (including assets, functions and processes) of water-dependent ecosystems at a low level of risk.
Ecological water provision	The water regime provided as a result of the water allocation decision-making process taking into account ecological, social and economic values. It may meet in part or in full the ecological water requirements.
Ecosystem	A community or assemblage of communities of organisms, interacting with one another, and the specific environment in which they live and with which they also interact (e.g. a lake). Includes all the biological, chemical and physical resources and the interrelationships and

	dependencies that occur between those resources.
Ectoparasite	A parasite that lives on the exterior of another organism.
Endemic species	Unique to a particular geographic location.
Euclidean distance	The distance as measured in Euclidean space; that is, as one would with a ruler. In the FARWH it is used to measure how different a reach is from the reference condition using information from the measures comprising of an index or sub-index (NWC 2007a).
Flow	Streamflow; may be measured as m^3/yr, m^3/d or ML/yr. May also be referred to as discharge.
Grab sample	Manual water sample obtained in a bottle for the purpose of analysing its water quality. Usually taken in flowing water just below, but not touching the surface.
Gravid	The condition of a fish when carrying eggs internally.
Habitat	The environment or place where a plant or animal naturally or normally grows or lives (includes soil, water, climate, other organisms and communities).
Limit of reporting	The limit of reporting is the minimum concentration of a substance that a laboratory will report based on statistically determined detection limits. Limits of reporting contain safety factors that allow commercial laboratories to handle variability associated with samples from a variety of sources.
Macrophyte (aquatic)	Rooted aquatic plants e.g. eelgrass.
Metal	For the purposes of this report, 'metal' refers to both metals and metalloids (arsenic).
Native species	A species occurring in a region or ecosystem as a result of natural processes only.
Nuptial colours	Colouring relating to mating or occurring during the mating season.
pH	A symbol denoting the logarithmic concentration of hydrogen (H) ions in solution. A measure of acidity or alkalinity in water in which pH 7 is neutral, values above 7 are alkaline and values below 7 are acid.
Refugia (in a waterways)	Sections of a stream that provide habitat and sufficient water quality and quantity to preserve aquatic biota during low flow periods.

Riparian vegetation	Vegetation growing along banks of watercourses, including the brackish upstream reaches of estuaries.
Sediment	Particulate matter settled on the bed of aquatic ecosystems
Substrate (in a waterway)	Physical substrate: the silt, sand and stone components of the streambed; biological substrate: organic matter such as woody debris, sticks, leaves and decomposing matter.
Surface water	Water flowing or held in streams, rivers and other wetlands on the surface of the landscape.
Taxa richness	Number of taxa in a sample or population.
Turbidity	Opaqueness of water due to suspended particles in the water causing a reduction in the transmission of light. The units of measurement are NTU (nephelometric turbidity units).
Type I error	Rejecting a correct hypothesis.
Type II error	Not rejecting a false hypothesis.
Urogenital papillae	A small tube near the anus through which eggs or sperm are released.
Water quality	The physical, chemical and biological characteristics of water. It is a measure of the condition of water relative to the requirements of one or more biotic species and/or to any human need or purpose.

Volumes of water

One litre	1 litre	1 litre	(L)
One thousand litres	1000 litres	1 kilolitre	(kL)
One million litres	1 000 000 litres	1 megalitre	(ML)
One thousand million litres	1 000 000 000 litres	1 gigalitre	(GL)

List of species reported in this study

Latin name (fish lifecycle category)	**Common name**	**Salinity preference**	**Native or exotic**	**Organism type**
*Nannoperca vittata**	Western pygmy perch	Fresh	Native	Finfish
Galaxias occidentalis	Western minnow	Fresh	Native	Finfish
Galaxiella munda	Mud minnow	Fresh	Native	Finfish
Bostockia porosa	Nightfish	Fresh	Native	Finfish
Tandanus bostocki	Freshwater cobbler	Fresh	Native	Finfish
*Cherax cainii***	Smooth marron	Fresh	Native	Crayfish
Cherax quinquecarinatus	Gilgie	Fresh	Native	Crayfish
Cherax crassimanus	Restricted gilgie	Fresh	Native	Crayfish
Cherax preissii	Koonac	Fresh	Native	Crayfish
Palaemontes australis	Freshwater shrimp	Fresh	Native	Shrimp
Chelodina oblonga	Western long-necked tortoise	Fresh	Native	Tortoise
Gambusia holbrooki	Mosquitofish	Fresh	Exotic	Finfish
Phalloceros caudimaculatus	One-spot livebearer	Fresh	Exotic	Finfish
Carassius auratus	Goldfish	Fresh	Exotic	Finfish
*Cherax spp. (yabby)****	Yabby	Fresh	Exotic	Crayfish
Psuedogobius olorum	Swan River goby	Fresh-Marine	Native	Finfish
Afurcagobius suppositus	South-western goby	Fresh-Marine	Native	Finfish
Leptatherina wallacei	Western hardyhead	Fresh-Marine	Native	Finfish
Geotria australis	Pouched lamprey ammocete	Fresh-Marine	Native	Lamprey

Notes:

* *Previously Edelia vittata*

** *Previously C. tenuimanus (Austin & Ryan 2002)*

*** *Conjecture over nomenclature – species collected could be Cherax albidus or Cherax destructor (specimen descriptions recorded for future identification)*

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