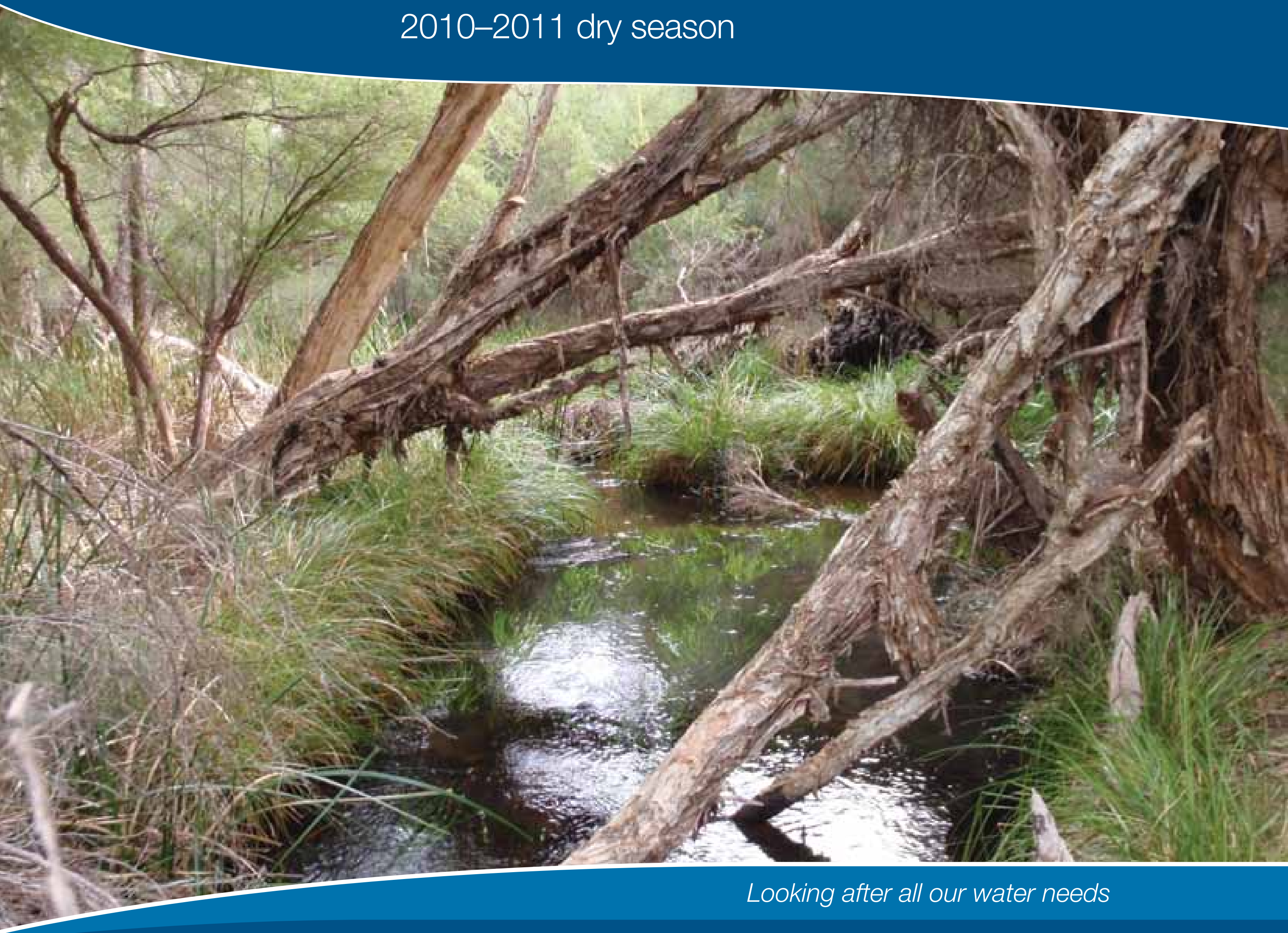
Government of Western Australia
Department of Water

Assessment of low-flow thresholds in maintaining the ecological health of the Lennard Brook

2010–2011 dry season



Looking after all our water needs

Water Science
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Report no. WST 42
August 2012

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Summary

The Lennard Brook is located in Western Australia's Gingin region and is a highly valued water resource for economic, cultural and environmental attributes – all of which have historically been supported by permanent flow. The brook supports one of the highest diversities of fish found in the state's south-west and includes both rare and endangered taxa.

Annual streamflow in the Lennard Brook has generally risen since the early 1970s: it has increased by 25% between the periods of 1963–1974 and 1975–2001. However, recent flow records demonstrate a decline of approximately 5% in annual average streamflow (based on comparison of flows between the 1975–2001 period and recent flows between 2008 and 2010). Future climate projections for the Gingin region project that streamflow will decrease by a further 30% by 2030 under a median climate scenario. Given that flows are decreasing in the surrounding area, stress from a drying climate may affect the brook's ecological health in future.

The long-term decline in streamflow in the Gingin region prompted the Department of Water to include a critical low-flow threshold (CLFT) for Lennard Brook in the *Gingin surface water allocation plan* (DoW 2011b). The CLFT is the flow below which it is predicted an ecological decline will occur. The CLFT was set in the allocation plan as 5 ML/day based on the 98th percentile of streamflow recorded in the brook between 1963 and 2001.

The Department of Water's Water Allocation Branch commissioned the Water Science Branch to assess the suitability of the 5 ML/day threshold, given that development of the threshold did not take into account future climate projections or measure relationships between flow and ecology in the brook.

Streamflow in the Lennard Brook during the study period was above the CLFT and therefore it was not directly possible to assess whether the 5 ML/day resulted in a decline in ecological condition. However, the results indicate that the flow regime assessed (minimum flow of 6.6 ML/day for one day, average 8.4 ML/day) was adequate to maintain the brook's ecological health – as demonstrated by the maintenance of good water quality, system connectivity (longitudinal and lateral) and relatively high fish diversity and biota condition. Surface water connectivity was identified as a potential threat to the future health of the brook given that some loss of aquatic habitat was observed when flows were below 6.6 ML/day.

Based on the results of this study, it is recommended a precautionary approach to managing the Lennard Brook resource be employed during low flows by implementing a daily flow trigger value of 6.6 ML (over two consecutive days) as an early warning sign of possible decline in ecological health. Following this, flows are to be monitored at the Molecap Hill gauging station on a weekly basis during low-flow periods to detect flows below this trigger. A breach in trigger value is recommended to prompt monitoring of the dissolved oxygen in selected river pools (likely refuge areas) to ensure levels are above the concentrations required to sustain aquatic

biota. Accordingly, the water quality trigger for dissolved oxygen should be set at 5 mg/L.

Revision of the low-flow trigger is expected in future based on the daily flow (ML) required for maintaining dissolved oxygen levels above 5 mg/L in refuge areas.

1 Introduction

The Lennard Brook is a perennial freshwater system that flows into several wetlands within the Bambanup Nature Reserve and Lake Yeal (DoW 2011b). The brook has a strong interaction with groundwater, with summer flows maintained by discharge from seeps and springs (Johnson 2000). Summer surface water flows are recognised as being important for preserving the brook's environmental (biodiversity, ecosystem processes), economic (e.g. agriculture) and cultural values (DoW 2011b, c).

Long-term average annual and monthly flows in the Lennard Brook show an increasing trend between 1963 and 2001 (monitored at Molecap Hill gauging station). This gauging station was closed in 2002 and re-opened in late 2008. Recent data from 2009 and 2010 indicates the streamflow may no longer be increasing. Long-term streamflow trends in the nearby Gingin Brook have also shown a declining trend since the mid-1970s: a trend also reflected in the mean annual rainfall (DoW 2011b, c). The response of flow in the Lennard Brook to abstraction and declining rainfall during the past 10 years is not clearly understood.

To protect system values the Department of Water set a preliminary critical low-flow threshold (CLFT) for the Lennard Brook in the *Gingin surface water allocation plan* (DoW 2011b). The brook's CLFT is a daily flow of not less than 5 ML for more than two consecutive days in a year (DoW 2011b), as recorded from the Molecap Hill gauging station (Figure 1).

The CLFT is a benchmark to monitor the summer flow regime and represents the point at which an unacceptable risk to water users and the environment has arisen. It was determined as the flow exceeded 98% of the time at the Molecap Hill gauging station between 1963 and 2001. This approach assumes that historic flows have been sufficient to protect the ecological values of the Lennard Brook, and that the CLFT is ecologically relevant.

Recent flow trends (2008–10) indicate the average annual and monthly streamflows may no longer be increasing. Future streamflows in the Gingin region are predicted to decrease by a further 30% by 2030 under a median climate scenario (CSIRO 2009). It is expected these thresholds will be reached more frequently in a future drier climate. Because of this it is important to validate the CLFT and check it is adequate to detect ecological degradation.

The study described in this report assessed the CLFT's suitability (as defined by hydrological trends) for maintaining the Lennard Brook's ecological health (ecosystem services, water chemistry, biotic composition and structure) and environmental values.

1.1 Objectives

The objectives of this study were to:

- investigate the suitability of the existing CLFT in maintaining ecological health in the Lennard Brook, with the view to revise it
- identify potential refugia within the brook as sites for future monitoring
- recommend an appropriate management response when the CLFT is reached.

1.2 Background

The Lennard Brook is a perennial system, with groundwater discharge maintaining surface water flow during the summer months. Most of the surface water is pumped directly from the watercourse during the summer for stock and domestic use, irrigated horticulture, cattle production and orchards (DoW 2011b).

A permanent flow regime is recognised as being vital for maintaining the brook's ecological and cultural values (Storey & Davies 2002).

Ecological values of the brook include:

- its connectivity with wetlands within Bampanup Nature Reserve including lakes Bambun and Yeal (DoW 2011b, c), which are valued for their conservation values and importance to waterbirds
- its high diversity of freshwater fish species, many of which are endemic to south-west Western Australia (Morgan et al. 1998, 2000)
- the presence of the rare and endangered mud minnow (*Galaxiella munda*) – this species has a very limited distribution and is classified as 'Restricted' by the Australian Society for Fish Biology (Morgan et al. 1998; Beatty et al. 2010).

Cultural values include indigenous mythological and burial sites of significance that exist in the resource area associated with the Lennard Brook. No social values that depend on flow have been identified (DoW 2011b, c).

1.3 Approach

Riverine ecosystem structure and function is strongly influenced by the flow regime (Puckridge et al. 1998). A reduction in flow can have a number of impacts on the aquatic environment, which can include:

- *Altered water quality such as increased electrical conductivity, increased diurnal variation in water temperature and decreased dissolved oxygen* (Lake 2003). Ecological consequences can include changes in the distribution and abundance of biota depending on the tolerances of differing species (McNeil & Closs 2007; Miller et al. 2007; Chessman 2003).
- *Decreased amount of available habitat through decreased wetted width, depth and flow* (Harvey et al. 2006; Hay 2009). Ecological consequences can include loss of taxa, particularly those with specialised requirements (Bunn & Arthington 2002).
- *Reduced lateral connectivity with the riparian zone and floodplain and reduced longitudinal connectivity affecting the sources and transfer of energy.* Ecological consequences include accumulation of organic matter (Boulton & Lake 1992) and changes in biotic composition due to varied allochthonous and autochthonous inputs (Reid et al. 2008; Walters & Post 2008).
- *Restricted distribution (migration) of biota between habitats and river reaches* (Bunn & Arthington 2002). Ecological consequences can include the increased importance of refuges in maintaining biotic biodiversity. Hence, sustainability relies on the maintenance of a number of good quality pools as refugia.

In assessing the adequacy of low-flow thresholds for maintaining the ecological health of the Lennard Brook, a multiple parameter assessment was chosen that encompassed physical, chemical and biological aspects. This approach was required to account for variability in streamflow and the associated direct, indirect, acute and chronic effects on ecological health.

Note: the health of refugia (as demonstrated by water quality and biotic condition) is a key determinant of low-flow stress and the associated recovery potential of the system (White & Storer 2012).

Fish and crayfish data were collected as biota are sensitive to specific environmental changes; can detect both acute and chronic conditions; and can respond to changes in water quality, hydrology and physical habitat structure (ANZECC & ARMCANZ 2000). For example, biological data (such as recruitment) can indicate system connectivity or habitat quality over recent years, whereas the presence of certain species may provide information on water quality conditions throughout the previous dry season.

Water chemistry, habitat availability and system connectivity were also monitored during the low-flow period to determine specific changes in response to flow.

All data were integrated with the gauged mean daily flow to investigate how flow interacted with the system's ecology.

1.4 Context

The findings of this study will be used in conjunction with the *Gingin surface water allocation plan* (DoW 2011b) to inform the Department of Water‘s decisions on allocation limits and licensing to protect the Lennard Brook water resource. This includes maintaining capacity for water supply to existing users and maintaining sufficient flow to preserve environmental values.

A separate report addresses the suitability of the upper Gingin Brook’s CLFT (see Galvin & Storer 2012). The Gingin Brook is one of six surface water allocation subareas that make up the whole *Gingin surface water allocation plan* area.

Note: a preliminary environmental water requirement (EWR) study has been conducted for the Gingin and Lennard brooks by Storey and Davies (2002). Due to a lack of streamflow data available during the period this study was conducted (2001 and 2008) the department could not confidently determine how the Lennard Brook water resource responded to abstraction and reduced rainfall. Hence the department decided the EWRs suggested by that study were not appropriate as a basis for allocation decisions until further streamflow data could be assessed (see DoW 2011c for further information).

2 Monitoring locations

This study focused on the Lennard Brook (Figure 1). Monitoring locations were selected to represent likely refugia occurring in the brook. Refugia are those sections of a stream that provide habitat and sufficient water quality and quantity to preserve aquatic biota during low-flow periods.

The Lennard Brook is a permanent system, with the majority of flow originating from groundwater discharge (DoW 2011c). Within the study area no natural pools occur but there are several off-stream (connected) dams. It is a largely connected system with the exception of the Molecap Hill gauging station (617165) and two private weirs in the brook’s upper reaches.

As there are no deep pools found in this system, the brook has been divided into two reaches: one monitoring site in the upper catchment, above most of the surface water abstraction; and another monitoring site downstream of the surface water abstraction (Figure 1, Table 1). The upstream site is located at the end of Lennards Road and will be used a reference for the downstream site. This site is deep compared with the brook’s other sections. The downstream site is located approximately 1.2 km downstream of Molecap Hill gauging station (Plate 1). A deep off-stream dam is used to abstract surface water located in the middle of the lower site. This dam does not pose a barrier to fish passage. For the purpose of the report, these sites will be referred to as upper and lower sites (Figure 1, Table 1).

Table 1 Monitoring sites sampled in the Lennard Brook.

Site	Location	Latitude	Longitude
Upper site	Lot 3311 Lennards Road, Lennard Brook	31.3816°S	115.9692°E
Lower site	Lot 1782 Brand Highway, Gingin (accessed by track off Cockram Road; opposite Lennards Road)	31.3861°S	115.9091°E

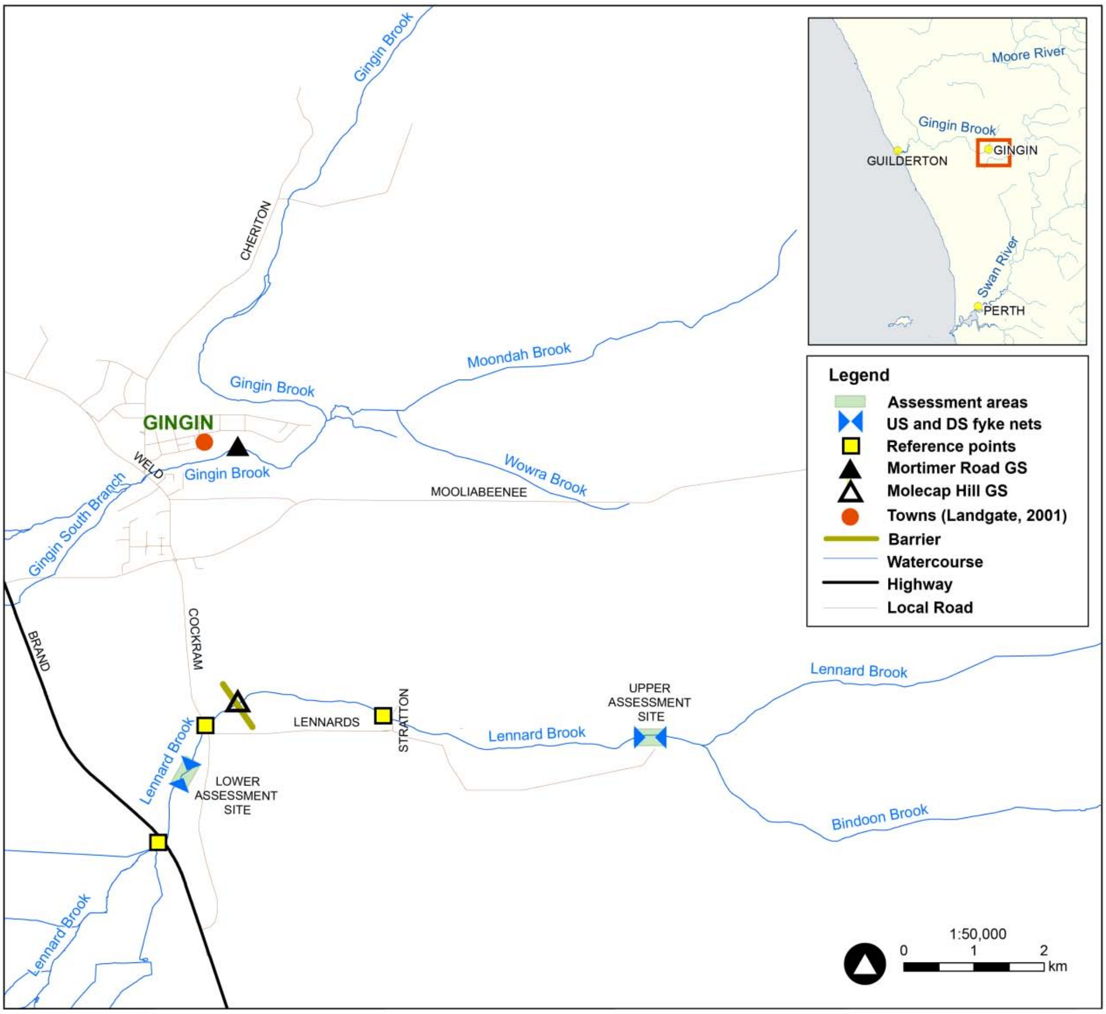


Figure 1 Study sites, in-stream barriers and gauging stations located on the Lennard Brook (US – upstream, DS – downstream, GS – gauging station).

Plate 1 Molecap Hill weir

3 Assessment method

Data on flow, stream connectivity, water chemistry, biota and habitat were collected to ascertain flow-ecology relationships for the Lennard Brook and used to evaluate the existing CLFT's suitability for maintaining ecological health. Data were collected through field sampling conducted monthly in February (23–24 upper site, 21–22 lower site), March (21–22 upper site, 23–24 lower site) and April (20–21 upper site, 18–19 lower site) and continuous measurements from water chemistry data loggers. The information collected included hydrology, stream connectivity, water quality, biota (fish and crayfish) and supporting environmental data. *In situ* water quality, stream connectivity and biota were collected monthly at both assessment sites. Continuous measurements of water chemistry were undertaken only at the lower assessment site for the entire duration of the study (4 February – 19 April). Monitoring schedules are explained further in the sections below.

3.1 Hydrology

Water levels and flows were monitored at the Molecap Hill gauging station (617165) between December and April and at several reference points established at each site.

Gauged data was collected to assess summer flows leading up to and throughout the study period. The reference point measurements for flow and depth were taken on each field sampling occasion using a Global™ flow probe and a 1 m ruler respectively to allow direct comparison against water quality and biota records. These were used to correlate flow at reference points to gauged flow to identify critical flows to meet environmental thresholds such as depth and dissolved oxygen concentration.

3.2 Stream connectivity

Stream connectivity incorporates longitudinal surface water flow, fish movement and lateral connectivity.

Longitudinal connectivity, in terms of biotic movement, is potentially impaired in the Lennard Brook due to the presence of Molecap Hill gauging station weir and two other private weirs located in the upper catchment. To quantify the degree of impact under low-flow conditions, longitudinal connectivity was assessed at several locations:

1. Molecap Hill gauging station was assessed using the Department of Water barrier assessment method (Storer et al. 2010a; 2010b) – see field sheets provided in Appendix B. Assessments determined the extent to which each fish species present in the Lennard Brook would be able to negotiate the barrier structure.
2. A number of additional reference points, typically at road crossings, were assessed each month over the study period (see Figure 1). At each point the

presence of flow and water depth was recorded. This was included to observe the connectivity of baseflow between major obstructions.

3. Photo points were also set up at each monitoring site. These were specifically targeted at observing the impact of flow change on water depth, wetted area, channel features and available fish habitat (habitat inundation). Photos were taken monthly (Appendix D). *Note: this assessed a combination of longitudinal and lateral connectivity (the latter being the linkages between habitats within the streamline, e.g. connection between pools and draping riparian vegetation or undercut banks).*

3.3 Water quality

Water quality loggers were deployed, and the data collected used to examine the relationship between changes in flow and water chemistry under low-flow conditions.

A single multi-parameter water quality datalogger (Manta™ 2) was deployed at the Lennard Brook's lower site for the duration of the study period (February to April). Dissolved oxygen, temperature, pH, specific conductivity and turbidity were recorded at 10-minute intervals. Data were downloaded and the equipment cleaned each month.

Dissolved oxygen and water temperature were also monitored at the upper site over the 24-hour field assessment period in February, March and April (10-minute intervals). This was done to examine localised water chemistry changes for comparability with biological information collected at each site. Data were collected using YSI 5739 oxygen/temperature probes attached to TPS WP-82Y dissolved-oxygen temperature loggers. Probes were placed into a PVC housing along with a small recirculating pump to ensure continual water movement over the probes' polarographic membranes. Calibration was conducted before initial deployment and at re-deployment after each field assessment.

Weather conditions (e.g. rainfall, cloud cover, wind) and water depth were also recorded to aid interpretation of temperature and dissolved oxygen data.

In situ spot readings and vertical depth profiling of dissolved oxygen, water temperature, specific conductivity and pH were recorded at several locations at each site to assess the effect of low flow on the general water quality in all parts of the river reach. Measurements were made using a Hydrolab Quanta multi-probe.

3.4 Fish and crayfish

Fish and freshwater crayfish were monitored to examine the relationship between changes in flow and fish abundance and diversity under low-flow conditions.

Fish and crayfish sampling was undertaken monthly between February and April. Two dual-winged fyke nets (rectangle mouth, opening 75 cm high and 105 cm wide, 3 mm mesh) were deployed over 24 hours on each sampling occasion: one placed on the upstream end of the sampling area and the other on the downstream end to capture fish migration into the study area. Fykes were placed near the centre of the stream channel with wings extending across the entire width of the stream. All fykes were set with a ball float at the end to enable surface access for air-breathing by-catch.

Five large and five small box traps (baited with chicken pellets) were also deployed within the 100 m section of the streamline delineated by fyke nets. Traps were left for 24 hours before retrieval. All in-stream habitat types present at each site were sampled to maximise collection of the full complement of fish and freshwater crayfish species present in the system.

Collected fish and crayfish were identified to species and assigned to a size class category (Appendix B). The following information was also recorded: evidence of reproduction; observations relating to their health and condition (i.e. staining, parasites, disease and injury); length of smallest-sized gravid individual; and length of largest individual. All native fish and crayfish were returned live to the water.

3.5 Additional environmental data

At each site detailed information was collected on aquatic habitat condition (e.g. woody debris, substrate characterisation, macrophytes); catchment condition (e.g. land use, impact of cattle, sources of pollution); physical form (e.g. erosion, channel form); riparian vegetation (e.g. width, presence of weeds, vegetative cover); and fish passage (barrier assessments). These assessments are taken directly from the South-west Index of River Condition (SWIRC) protocol developed by the Department of Water (Storer et al. 2011a, b). See Appendix B for the SWIRC river health assessment field sheets used.

These data were used to characterise the habitat conditions in the brook and provide a general indication of the condition of the reach and catchment. Data were used for the interpretation of results and, as such, have only been referred to in support of observations made about water chemistry and fish/crayfish assemblage.

4 Results

4.1 Hydrology

Streamflow in the Lennard Brook remained above the CLFT of 5 ML/day for the entire duration of the study: flows ranged from 6.6 to 12.1 ML/day. There was an evident decline in flow during January to late March, with the lowest flow (6.6 ML/day) recorded on 22 February (Figure 2).

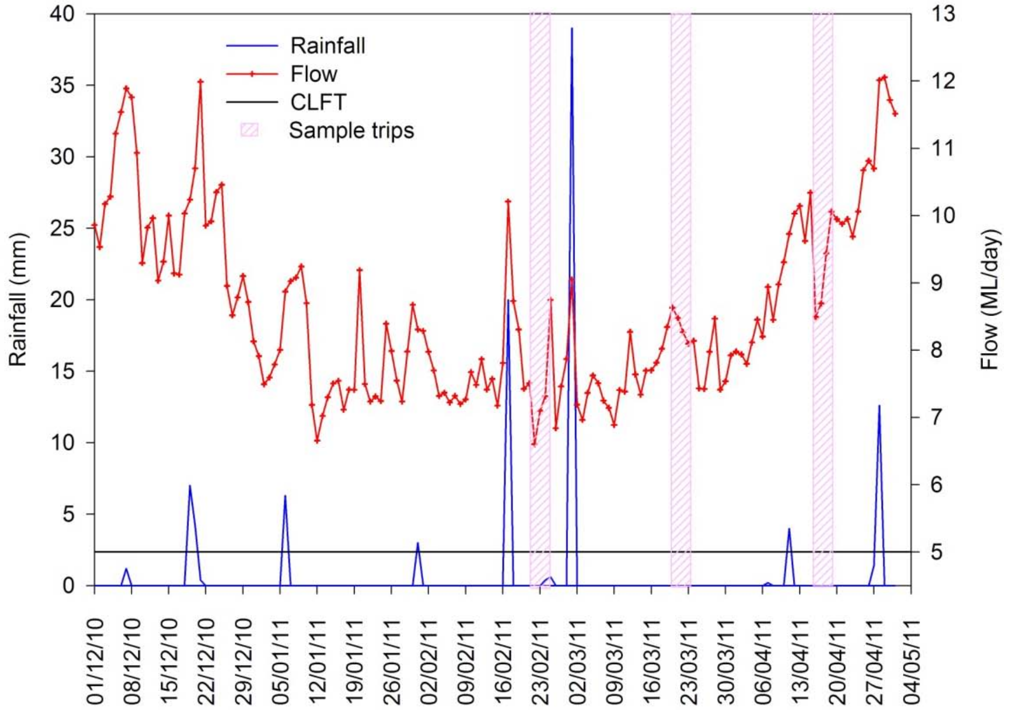


Figure 2 Lennard Brook – daily flow from Molecap Hill gauging station (617165) and daily rainfall from the Gingin meteorological station (9018) during December to April 2011. Pink shading indicates sampling occasions.

4.2 System connectivity

Flows in Lennard Brook were generally adequate to maintain both longitudinal connectivity and water depth for maintaining aquatic habitat (e.g. woody debris, submerged macrophytes and draping vegetation). In February a drop (5 cm) in water levels was observed over the two-day sampling period at the lower site. At the time flows were at their lowest – 6.6 ML/day. This drop in flow resulted in a decrease in the lateral inundation of the stream habitat, disconnecting draping vegetation and exposing some areas of large woody debris. Exposed habitat is clearly shown in photographs (see Appendix D and Figure 11 and Figure 12).

Fish movement was unaffected by the low-flow conditions experienced throughout the study period with the exception of the Molecap Hill weir. Under summer low-flow conditions it is likely this weir impedes all fish movement. However, during high flows migration is not likely to be impeded given that barriers appear to drown out. Anecdotal evidence suggests that fish movement may be impeded in the brook's upper reaches. No barrier survey was undertaken but it is likely an in-stream barrier is located downstream of the upper assessment site.

4.3 Water quality – dissolved oxygen

Dissolved oxygen concentrations recorded at the lower Lennard Brook assessment site displayed a gradually increasing trend over the study period, with concentrations typically ranging from approximately 7 mg/L in February through to 8.5 mg/L in April (Figure 3Figure). Rainfall events in February (Figure) preceded a rapid decrease in dissolved oxygen concentrations; in particular, levels dropped from above 7 to 4.5 mg/L after 20 mm of rainfall on February 16. Oxygen concentrations quickly recovered in the brook to levels above 5 mg/L within 12 hours of the rainfall event.

Diel changes in dissolved oxygen concentrations were monitored monthly at the upper site (Figure 4Figure). No dissolved oxygen data are available for February due to equipment calibration problems. However *in situ* spot measurements indicate that dissolved oxygen levels were above 7 mg/L in February.

Dissolved oxygen levels in March were variable, with concentrations varying between approximately 5.6 and 7.2 mg/L through the 24-hour period (Figure 4Figure). Diel oxygen concentrations in April show a distinctive diurnal curve. Dissolved oxygen was maintained at adequate concentrations with levels staying above 6.5 mg/L. Flows recorded at this time were 9.9 ML/day (Figure 3).

Both sites on the Lennard Brook maintained dissolved oxygen levels well above thresholds known to cause stress to aquatic fauna (5 mg/L) (ANZECC & ARMCANZ 2000; Hunt & Christiansen 2000; Koehn & O'Connor 1990) throughout the study period.

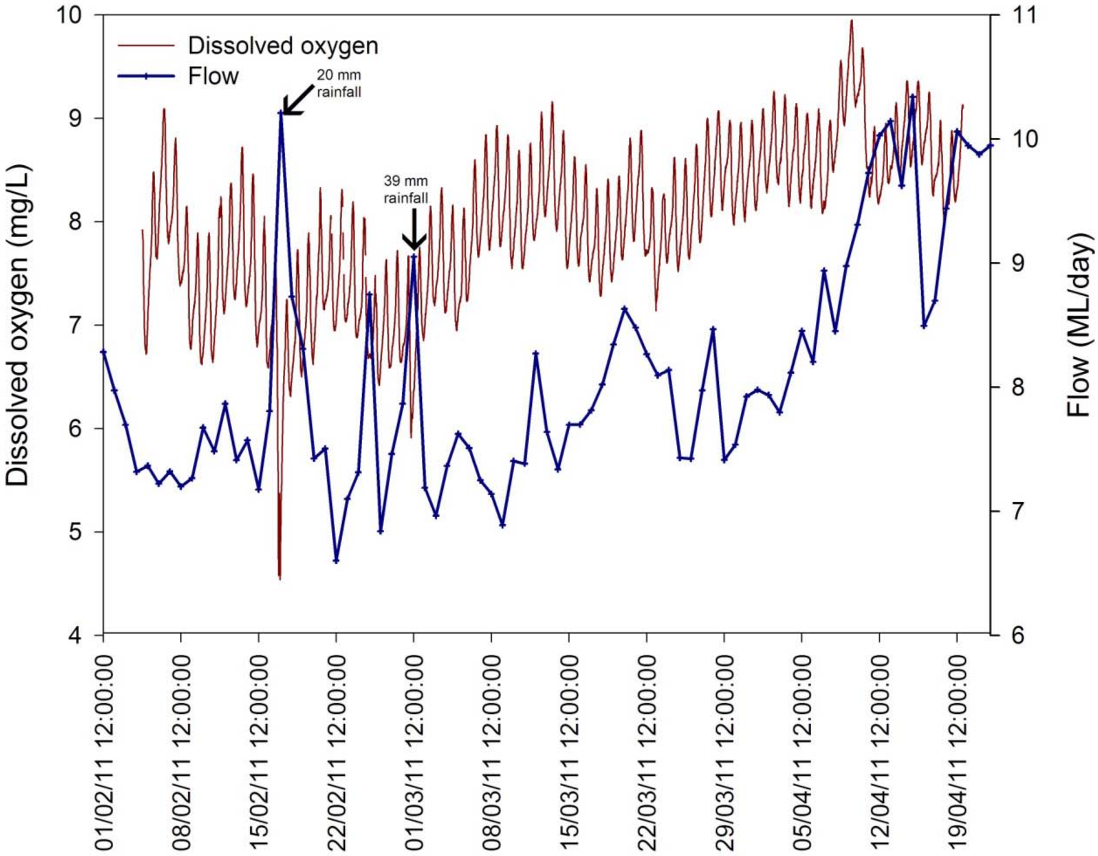


Figure 3 Dissolved oxygen at the lower site on the Lennard Brook relative to gauged flow at Molecap Hill gauging station. Major rainfall events are indicated on the plot.

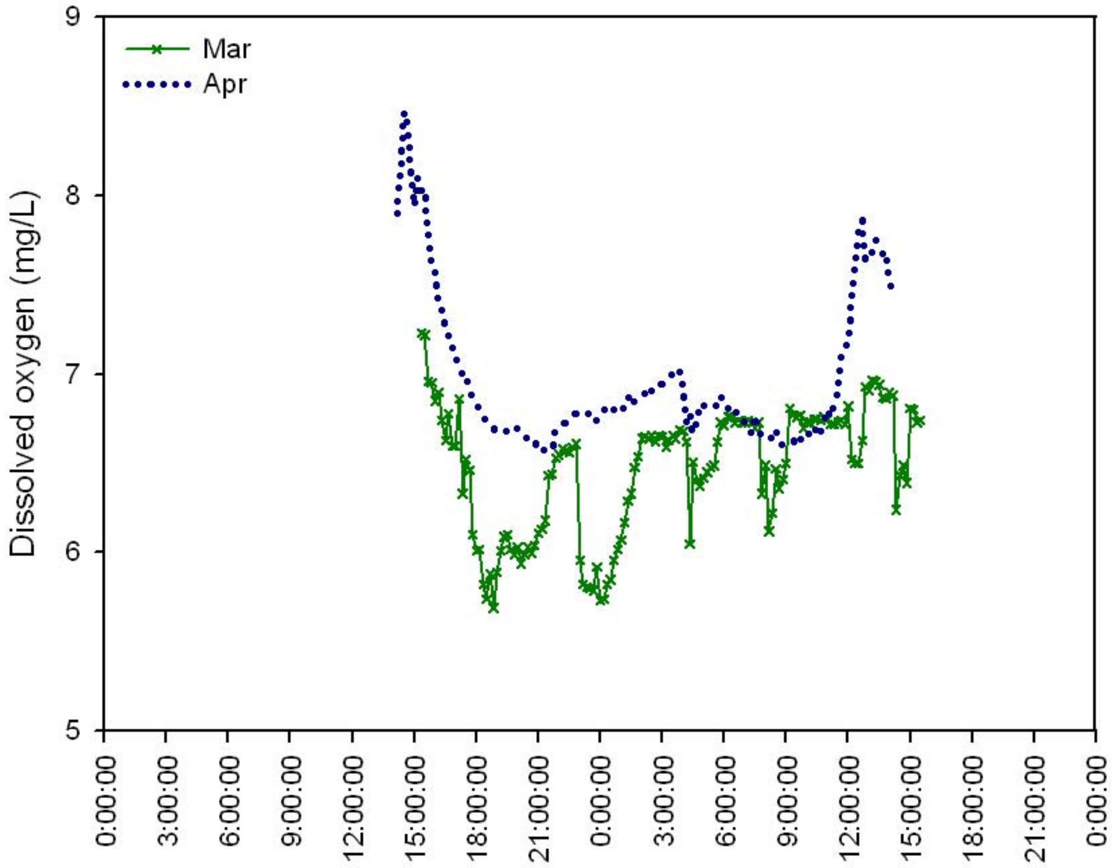


Figure 4 Diel dissolved oxygen at the upper site on the Lennard Brook.

4.4 Other water quality variables

The Lennard Brook's electrical conductivity (measured at the lower site) remained around 0.9 m^S/cm throughout the study period (Figure 7, Appendix C). This is within the freshwater range (0–1 m^S/cm) (ANZECC & ARMCANZ 2000). Pulses of increased salt content were recorded in February after a large rainfall event, indicating potential inputs of salt via runoff from the cleared areas of the catchment.

The pH of the brook (measured at lower site) was between 6 and 7 for the study period (Figure 8, Appendix C) which is within optimal ranges for south-west systems (ANZECC & ARMCANZ 2000).

Equipment failure resulted in erroneous results for turbidity (measured at the lower site) and thus no data have been presented. The water was very clear during the study period (February to April) at both sites; relatively low levels of turbidity were observed.

4.5 Fish and crayfish assemblages

A total of five native fish, two native crayfish and one introduced species (mosquitofish, *Gambusia holbrooki*) were recorded in the Lennard Brook across both sites during the study period (February to April). Native species collected were freshwater cobbler (*Tandanus bostocki*), western pygmy perch (*Nannoperca vittata*; formerly *Edelia vittata*), nightfish (*Bostockia porosa*), western minnow (*Galaxias occidentalis*) and western hardyhead (*Leptatherina wallacei*).

Freshwater cobbler was only recorded at the brook's upper site (Figure 5). Large numbers were observed migrating upstream in February and March: 98% and 71% of the catch respectively. No downstream movement was recorded, which suggests that freshwater cobbler remained in the brook's upper reaches.

The population of freshwater cobbler in the brook appears to be recruiting successfully, as suggested by a wide size range of individuals captured, including juveniles (<100 mm TL) (Figure 6).

Other native fish recorded at the upper site consisted of western pygmy perch and nightfish (Figure 5). The abundance for both species was low and remained similar throughout the study period. The western minnow, a common and widespread native species in south-west Western Australia, was not recorded at the upper site.

The mosquitofish was only recorded in March in low abundance at the upper site.

Both the freshwater crayfish species – gilgie (*Cherax quinquecarinatus*) and marron (*Cherax caiini*) – were collected at the upper site (Figure 5). A large number of marron were recorded in February, with 31 individuals caught. Marron numbers decreased in March and abundances remained similar in April. Marron were more abundant at the upper site, which is likely due to the presence of more complex habitat and deeper water depth.

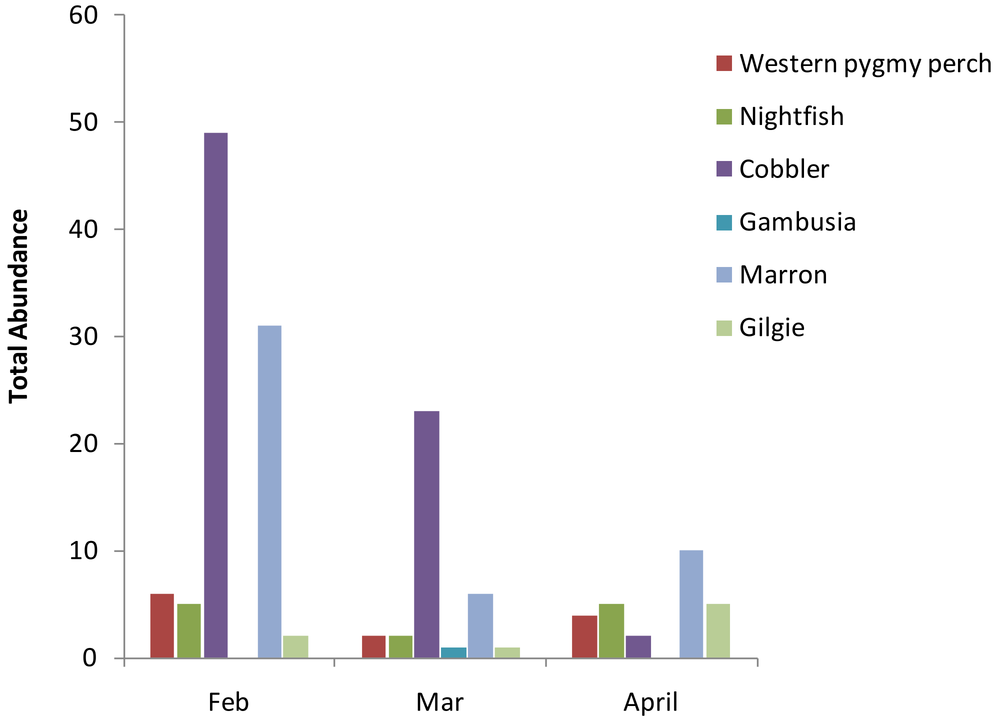
The native fish assemblage at the lower site consisted of western pygmy perch, western minnow, nightfish and western hardyhead (Figure 5). The western pygmy perch was the most abundant fish species in February with 58 individuals collected. Western pygmy perch were observed schooling in large numbers (10–12 individuals) during February. Western minnow abundance increased over the study period but nightfish abundance remained fairly consistent between seven and eight individuals. An estuarine species, the western hardyhead (*Leptatherina wallacei*), was recorded in low abundance in February at the lower site.

Both the freshwater crayfish species – gilgie and marron – were collected at the lower site (Figure 5). Gilgies were consistently observed in similar numbers throughout the study period. Marron were only recorded in February.

The exotic mosquitofish (*Gambusia holbrooki*) was present throughout the study period at the lower site. It was predominantly observed in the off-stream dam where flows were slower.

The populations of western minnow, western pygmy perch, nightfish and freshwater cobbler in the Lennard Brook appear to be recruiting successfully – as suggested by a wide size range of individuals being captured at both sites (Figure 6). With the exception of the freshwater cobbler, no migration trends were observed for the other native fish species (western pygmy perch, western minnow and nightfish).

Upper assessment site



Lower assessment site

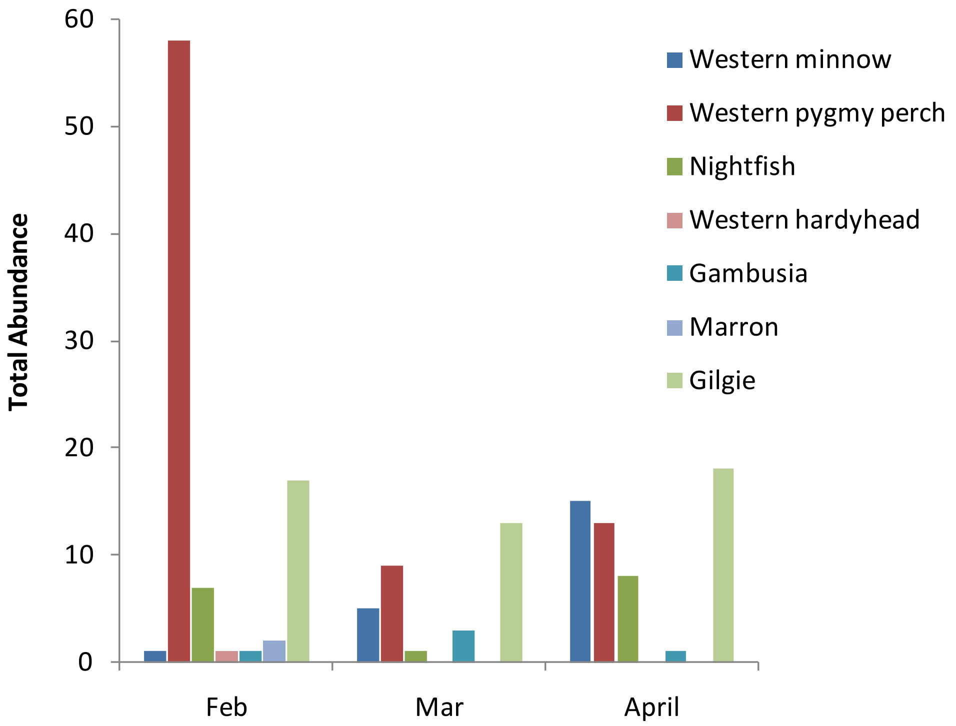
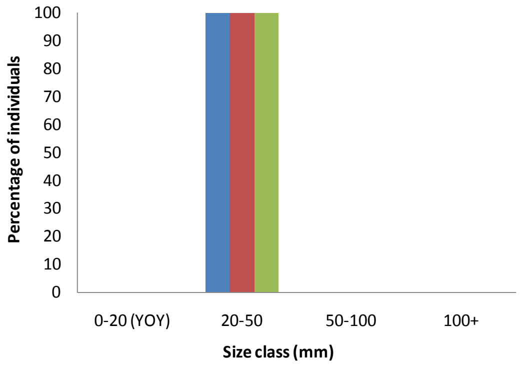
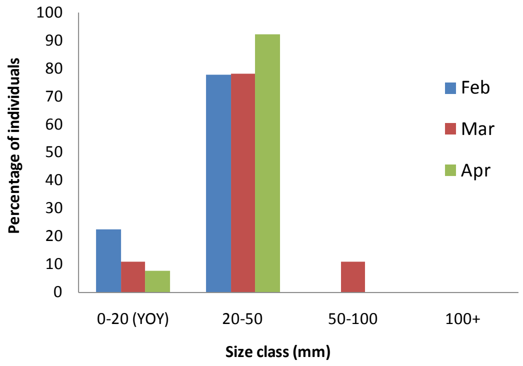


Figure 5 Fish fauna assemblage at the upper and lower sites on the Lennard Brook.

Upper site *Lower site*

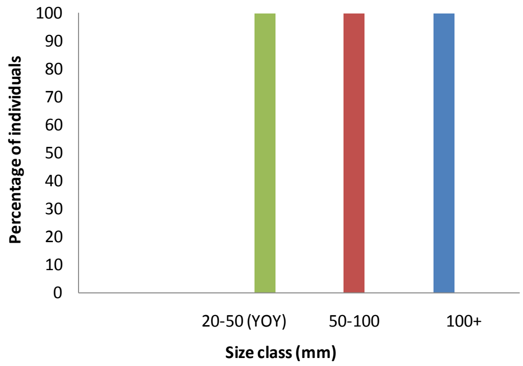
Western pygmy perch



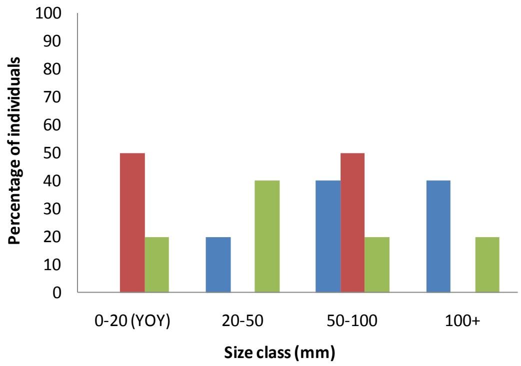


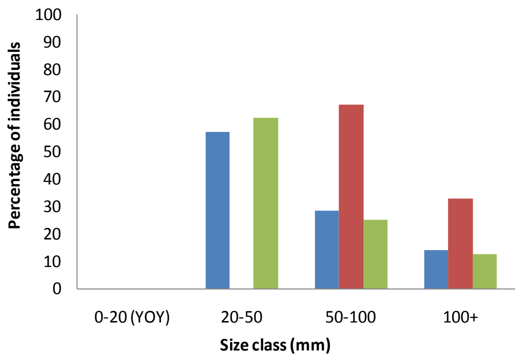
Western minnow

Absent from upper site

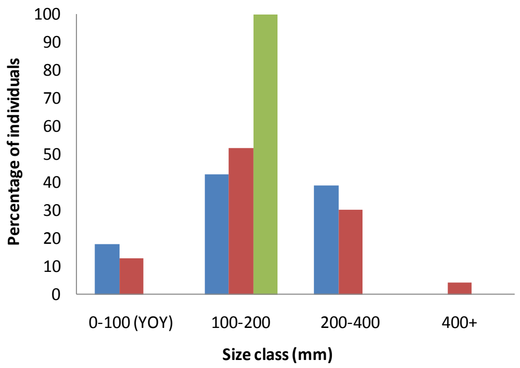


Nightfish





Freshwater cobbler



Absent from lower site

Figure 6 Size class frequency distributions for the freshwater fish in Lennard Brook (YOY – young of year).

4.6 Additional observations

The Lennard Brook's catchment has been cleared for agriculture and horticulture. Unlike the Gingin Brook, large portions of the riparian vegetation are intact and in relatively good health. The riparian vegetation's condition ranged from near pristine to slightly disturbed. There are some isolated areas where the riparian vegetation has been degraded and consists of scattered trees and weed-dominated understorey.

The riparian vegetation at the lower site is dominated by scattered *Melaleuca rhaphiophylla* and *Eucalyptus rudis.* The understorey is more degraded compared with the upper site: some native sedges are present but it is largely dominated by dense exotic grasses. The in-stream vegetation consists mainly of draping exotic grasses and some areas of draping sedges. Much large woody debris is found at the site. Detrital material is less dense compared with the upper site. It was typically found in slower-flowing areas of the channel, particularly in the off-stream dam. The sediment in the dam is anoxic in places; bubbles rising from the sediment were observed in February. Large amounts of fine silt were also observed in the off-stream dam. Water depth at this site ranged between 0.28 and 0.36 m, with the lowest depth observed in February. Water depth in the off-stream dam was deeper at 0.6 to 0.7 m.

The riparian vegetation at the upper site is relatively undisturbed and dominated by *Melaleuca rhaphiophylla* and *Eucalyptus rudis*. The riparian buffer width extends more than 50 m from the bank. The understorey is relatively intact with some minor weeds present. The in-stream vegetation consists of both draping emergent macrophytes and large areas of the submerged macrophyte *Triglochin procerum*. The brook contains much large woody debris and the substrate is covered in deep, dense detrital material (dominated by melaleuca debris). The water depth at this site was deeper than the lower site and ranged between 0.66 and 0.79 m during the study period.

5 Discussion

The Lennard Brook is a typically shallow system with no obvious natural deep pools (areas >1 m not observed, with the exception of a few off-stream dams), hence any change in flow has the potential to result in significant changes to the ecology. For instance, a relatively minor reduction in flow could elicit a rapid disconnection and subsequent drying through large sections of the system, with limited ability for biota to retreat to refugia that would sustain other systems under similar circumstances. Accordingly, the brook is at particular risk under a drying climate scenario.

The summer flows recorded during this study were adequate to maintain the ecological values and health of the Lennard Brook by way of good water quality, system connectivity (longitudinal and lateral/habitat inundation) and relatively high fish diversity and biota condition. However, flows remained above the CLFT during this period. Further, this study identified a few concerns (e.g. reduced lateral connectivity of surface water at the lower site, in-stream barriers affecting fish passage, localised accumulation of organic material and silt in the off-stream dam) that may affect the sustainability of ecosystem health under the current CLFT.

The results of the study are discussed in detail below against each of the indicators – fish assemblage, connectivity (longitudinal and lateral/habitat inundation) and water quality – for assessing the Lennard Brook's ecological health in terms of the adequacy of the current flow regime.

Fish assemblages

The fish fauna of the Lennard Brook are diverse on a south-west Western Australian scale, with a total of five native species recorded during the low-flow period, all of which are endemic to the region. All species expected to occur in the brook (given previous records by Morgan et al. 2000 and Beatty et al. 2010) were collected with the exception of the mud minnow (*Galaxiella munda*). The mud minnow has been classified 'Restricted' by the Australian Society for Fish Biology. The absence of mud minnow was not surprising since the likelihood of capturing this species is low, given it is typically extremely rare within its distribution range, and is generally found in tributaries and ephemeral pools not sampled in this study. However, Morgan et al. (2000) suggest the mud minnow could be in decline as a result of habitat degradation. Habitat degradation was minor at the brook's upper site but some signs of degradation, mainly weed infestation of the riparian vegetation, were apparent at the lower site.

Freshwater cobbler were abundant at the brook's upper site but none were recorded at the lower site. The population at the upper site appeared viable, with successful recruitment indicated by many individuals < 100 mm TL (juveniles) (Figure 5 and Figure 6). Based on numbers of freshwater cobbler caught in fyke nets, small groups appear to be migrating upstream predominantly during February and March. Given that reproductive condition was not advanced it is likely that migrations are due to food and/or habitat selection. This trend is consistent with observations from the adjacent Gingin Brook, with a peak in migration around February (Galvin & Storer 2012).

Freshwater cobbler have not been previously recorded in the Lennard Brook (Beatty et al. 2010; Morgan et al. 2000) and given this, it is difficult to interpret the cause of the absence from the lower site. The absence could be due to natural conditions relating to seasonal migration (although some individuals would still generally be expected – Storer pers. comm.) or upstream habitat preference, or this could be due to anthropogenic causes such as habitat degradation or fish passage impediment due to in-stream barriers. Given the brook's ecological health is high and the known barriers are unlikely to be a permanent barrier to migrating fish (the barrier appears to drown out in high flows), it is likely their absence is due to the natural range not including the brook's lower section or another factor not observed in this study. Freshwater cobbler was not recorded at the upper site in April. This may indicate that the population remained in the middle reaches of the system, potentially due to habitat preference or barrier effects during summer. Monitoring of freshwater cobbler movements within the Lennard Brook and a barrier survey to identify and characterise in-stream structures will improve our knowledge of cobbler migration in the system.

The data collected during this study indicate the populations of western pygmy perch, nightfish and western minnow are reproducing, since both adults and juveniles (young of the year) were captured. Hence, these populations appear sustainable under the current flow conditions. Western minnows were only captured at the lower site, which may be due to either natural variation (e.g. seasonal migration patterns) or an in-stream barrier affecting access to the upper reach. The upper site assessed in this study is the furthest upstream that monitoring has taken place compared with previous studies in the area (Beatty et al. 2010; Morgan et al. 2000). As such, there is no relevant baseline to compare distribution of the western minnow. A similar study by Beatty et al. (2010) in the previous dry season recorded western minnows approximately 2 km downstream of the upper site monitored in this study. As such, if the absence of western minnows from the upper site is due to an in-stream barrier it would occur within this 2 km section (anecdotal evidence supports the presence of a barrier in this section). This observation is consistent with studies on the adjacent Gingin Brook where western minnows were only captured below the Gingin Brook gauging station weir at Mortimer Road (Galvin & Storer 2012; Beatty & Morgan 2004; Morgan et al. 2000). Further work is required to determine if western minnow movement is being obstructed by the presence of in-stream barriers in the Lennard Brook.

Stream connectivity

Surface water connectivity (longitudinal and lateral) is essential for maintaining biotic populations and hence the ecological health of the Lennard Brook. It is a requirement of fish, crustaceans and other biota to move within a system to gain access to habitat and food, complete lifecycles and maintain population dynamics and genetic diversity (Norton & Storer in press). Loss of connectivity can result in isolation of populations, failed recruitment and local extinction of fish species (Fairfull & Witheridge 2003; Bunn & Arthington 2002).

The longitudinal connectivity of surface water was maintained throughout the study period and flows were generally sufficient for maintaining inundation of a representative spread of aquatic habitat. A loss of some aquatic habitat – primarily exposure of draping vegetation and large woody debris on the stream edge – was observed during February at the lower site when flows were their lowest at 6.6 ML/day (see Appendix D and Figure 11 and Figure 12). However, a complete diversity and complexity of habitat was represented through all monitoring periods and no obvious biotic impacts were observed. This extent of lateral disconnection does not appear to produce adverse effects on system health.

In-stream barriers on the brook also alter the connectivity of the surface water. Based on the barrier assessment undertaken in this study, the weir structure at Molecap Hill gauging station poses an obstruction to fish migration during summer low flows, but is likely to be drowned out in higher flows. As no obvious impacts on recruitment of native fish species were observed within this study, it appears that fish populations are self-sustaining. This implies that system connectivity is sufficient under the current flow conditions. However, if low-flow conditions further reduce (particularly below the 6.6 ML/day minimum recorded in this study) it may increase the level of disconnection, particularly in the shallower lower section. This may impact fish populations either directly through impediments to migration or due to decline in environmental health caused by reduced flushing (discussed below in water quality) or through changes in community interactions (e.g. increased competition/predation a result of reduced habitat availability).

As outlined in the introduction of this section, the brook's ecological health is at high risk from reduced flows because it is characteristically shallow and has no obvious deep refugia. Given the implied limitations in resilience of the system to declining streamflows, assignment of an appropriate flow trigger based on connectivity (including depth over habitat and in-stream barriers) is important. This requires an increased understanding of surface water connectivity when flows are below 6.6 ML/day.

Two private weirs located in the brook's upper reaches were not assessed in this study. Their exact location is unknown. Whether these structures are an impediment to fish passage is therefore also unknown. Any future barrier assessments should include them.

Water quality

Water quality in the Lennard Brook was maintained within acceptable levels for aquatic biota health based on available relevant guidelines (encompassing ANZECC & ARMCANZ 2000; Hunt & Christiansen 2000; Koehn & O'Connor 1990) throughout the study period. However, there are some minor concerns that the future water quality and health of the brook may deteriorate given observations of organic material and silt accumulating within the areas assessed, particularly in the off-stream dam at the lower site.

Accumulation of organic material and sediment has the potential to adversely affect both water quality and habitat availability. The primary concern relates to oxygen depletion due to the process of decomposition of the organic matter (bacterial respiration). Accumulation of organic material is a natural ecosystem recycling process, however, anthropogenic modification often results in an increased rate of accumulation (due to land clearing and restricted flushing under reduced flow conditions) and deposition can often be exaggerated in localised areas because of the presence of man-made obstructions. This is clearly evident in the nearby Gingin Brook where organic material and silt has accumulated in pools above in-stream barriers and caused a localised deterioration of water quality and habitat (Galvin & Storer 2012). In the Lennard Brook accumulation of organic material and silt was observed in the off-stream dam located at the lower site, but it is not prevalent elsewhere (beyond natural expectations). Within the dam site, release of bubbles from the sediment was observed, possibly indicating the release of hydrogen sulfide gas which can cause depletion in dissolved oxygen.

This study suggests that if the current flow regime continues it is unlikely to adversely affect the health of the Lennard Brook. However, it is difficult to predict whether the system’s health will be affected in subsequent years of similar flow or if flows reduce further. It is therefore important to monitor system health (water quality and biotic assemblages) in subsequent low-flow years to assess chronic changes in the system.

5.1 Management of the CLFT

The overall objective of this study was to assess the existing CLFT’s suitability (as defined by hydrological trends) for maintaining the Lennard Brook’s ecological health and environmental values.

During this study flows were consistently above the CLFT, therefore it was not possible to directly evaluate whether the daily threshold of 5 ML (over two consecutive days) was adequate to maintain the Lennard Brook’s ecological health and environmental values. Based on the results of this study, flows above 6.6 ML/day in the brook appear to maintain a healthy ecosystem and do not appear to elicit any signs of significant ecological stress. If the current flow regime continues it is unlikely to affect the system’s health.

However, since a decline in habitat availability and water depth was observed at the lower assessment site when flows were at 6.6 ML/day (and the system is naturally unequipped to deal with significant reductions in depth given its shallow nature and lack of refugia), it is difficult to infer an appropriate low-flow trigger value below this level. As such, ecosystem responses to sub-6.6 ML flows (particularly water quality and system connectivity) need to be investigated to review the existing CLFT. In the interim it is recommended a precautionary approach to managing the Lennard Brook resource be employed during low-flow regimes by implementing a daily flow trigger value of 6.6 ML (over two consecutive days) as an early warning sign of a possible decline in ecological health. When this occurs, flows are to be monitored at the Molecap Hill gauging station on a weekly basis to detect flows below this trigger. A breach in trigger value is recommended to prompt monitoring of the dissolved oxygen in selected river pools (likely refuge areas) to ensure levels are above concentrations required to sustain aquatic biota. Accordingly, the water quality trigger for dissolved oxygen should be set at 5 mg/L.

Revision of the low-flow trigger is expected in future based on the daily flow (ML) required to maintain dissolved oxygen levels above 5 mg/L in refuge areas.

A response strategy to a breach in prescribed threshold has been provided in Appendix E.

5.2 Recommendations

1. Replace existing CLFT with a precautionary flow trigger value of 6.6 ML/day recorded over two consecutive days (monitored at the Molecap Hill gauging station). Breach of this trigger would initiate a monitoring response to determine whether flows below this level are impacting system health, with a focus on assessing dissolved oxygen levels at selected sampling sites.

   It is recommended that dissolved oxygen levels below 5mg/L elicit a more comprehensive ecological assessment (including biological response), with the specific response to be determined by a meeting of staff from the region and the Water Allocation and Water Science branches.

   Dissolved oxygen levels above 5mg/L at flows below 6.6 ML/day should result in a re-designation of the flow trigger: the new trigger value derived should be based on sufficient flow to maintain dissolved oxygen above 5 mg/L (incorporating diurnal fluctuation).

   A detailed response strategy following breach of the precautionary flow trigger is provided in Appendix E.

2. Maintain regular monitoring of the daily flow at the Molecap Hill station (617165) to identify when flows are below the trigger.
3. Protection of the refuge areas is important for maintaining the Lennard Brook’s ecological health. Consideration should thus be given to restricting surface water and groundwater abstraction near refugia and encouraging surface water users to abstract water from the brook during the winter high flows to reduce the reliance on summer flow.

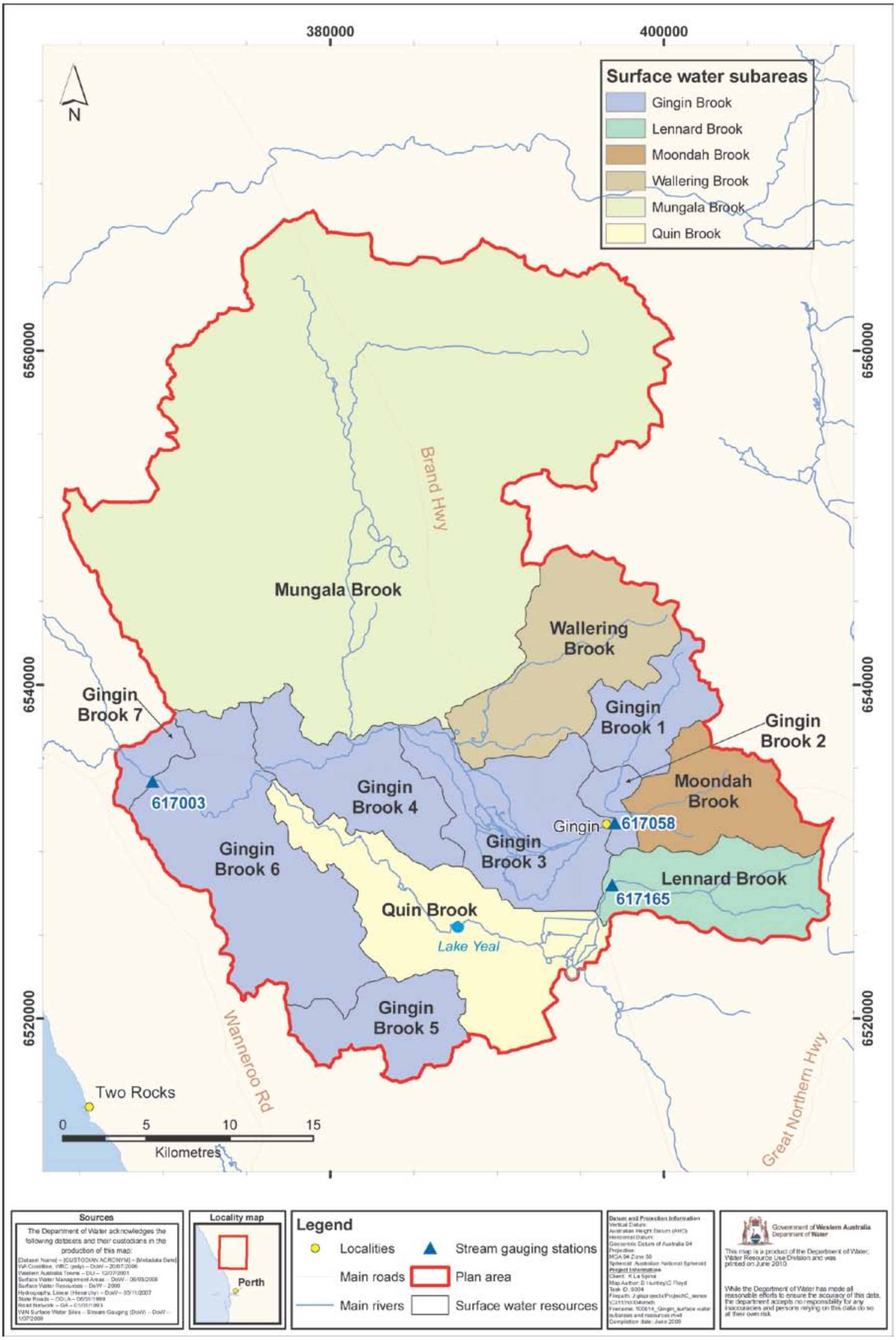
5.3 Knowledge gaps and management priorities

Based on the results of this study, a number of knowledge gaps and management actions were identified as areas for future investigation for enhancing our ability to better manage and maintain or improve the Lennard Brook’s ecological health. These include:

1. Assessment of the connectivity of surface water in terms of fish movement. This should also include an in-stream barrier assessment.
2. Maintenance of refuge areas that are critical to the long-term sustainability of the Lennard Brook (assessment of key refugia in the system is required).
3. Monitoring of inorganic and organic sediment levels above and below in-stream barriers to evaluate whether system flushing is adequate to maintain water quality and habitat.

Appendices

Appendix A — Surface water allocation subareas and surface water resources



Source: Department of Water (2011b).

Appendix B — SWIRC river health assessment 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

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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 ☐

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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			

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
GENERAL SITE ASSESSMENT – 100m sampling site

CROSS SECTION DIAGRAM

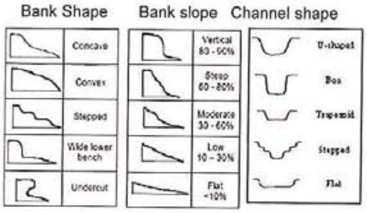
Representative of sampling region (where high variability exists draw two cross-sections).

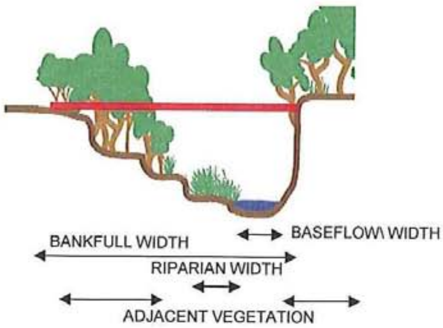
Suggested information to include on cross section diagram above

- 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

Bank Shape Bank slope Channel shape





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)	

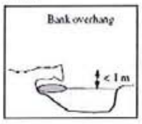
*Note: section relates to habitat (not shading). ** Dead vegetation not included*

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.

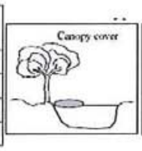
Flow (circle)
Uniform flow (e.g. drain)
Moderately varied flow
Varied flow (eg eddies, backwaters, fast, slow)

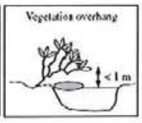
Depth (circle)
Uniform depth (eg drain)
Moderately varied depth
Varied depths



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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Date ________________ Site code ________________

Government of Western Australia
Department of Water

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		
Ground layer (i.e. sedges, rushes)	yes	no	reduced
Shrub layer (woody)	yes	no	reduced
Tree layer	yes	no	reduced

Width of riparian zone Left bank ______m Right bank ______m

Dominant riparian species (if unknown write: refer to photographs):

* 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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Date ______________ Site code ______________

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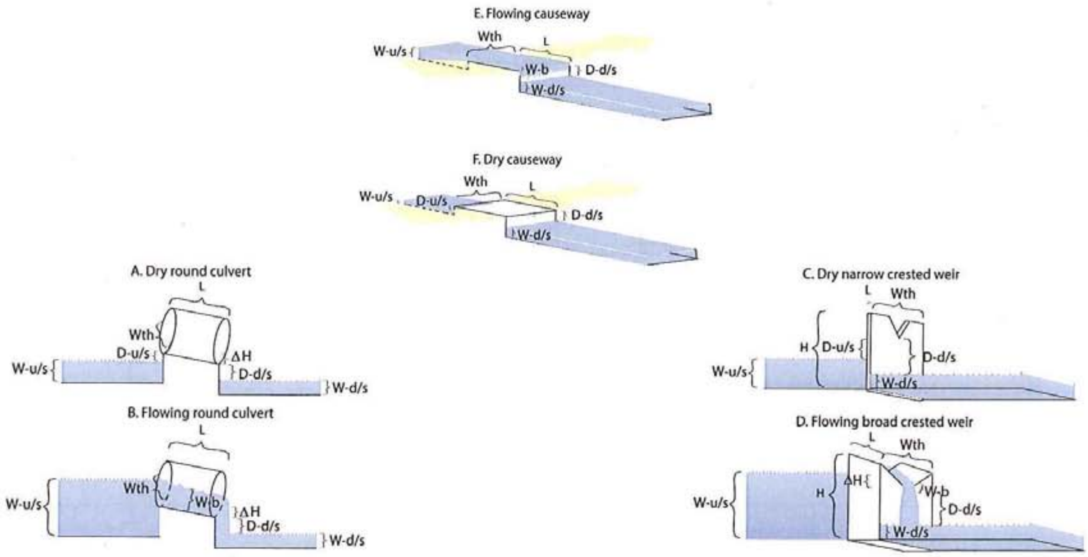
SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
BARRIER ASSESSMENT - 100m sampling site

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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Date ______________ Site code ______________

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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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Date ________________ Site code ________________

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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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Date ______________ Site code ______________

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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 ____________

Government of Western Australia
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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)
	Fish	0-20	20 - 50	50 - 100	100 +	Other	none	• staining, parasites, disease, injury
	Crayfish	0-20	20 - 50	50 - 76	76 - 100	100+	✓ (few)	• smallest size gravid individual • size of largest individual
	Large fish	0-100	100-200	200-400	400+	Other	✓✓ (many)	***Note size of marron over 76mm***

**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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[additional sheets provided in field kit; explaining disparity in page numbers]

Date ________________ Site code ________________

Government of Western Australia
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 C — Water quality graphs

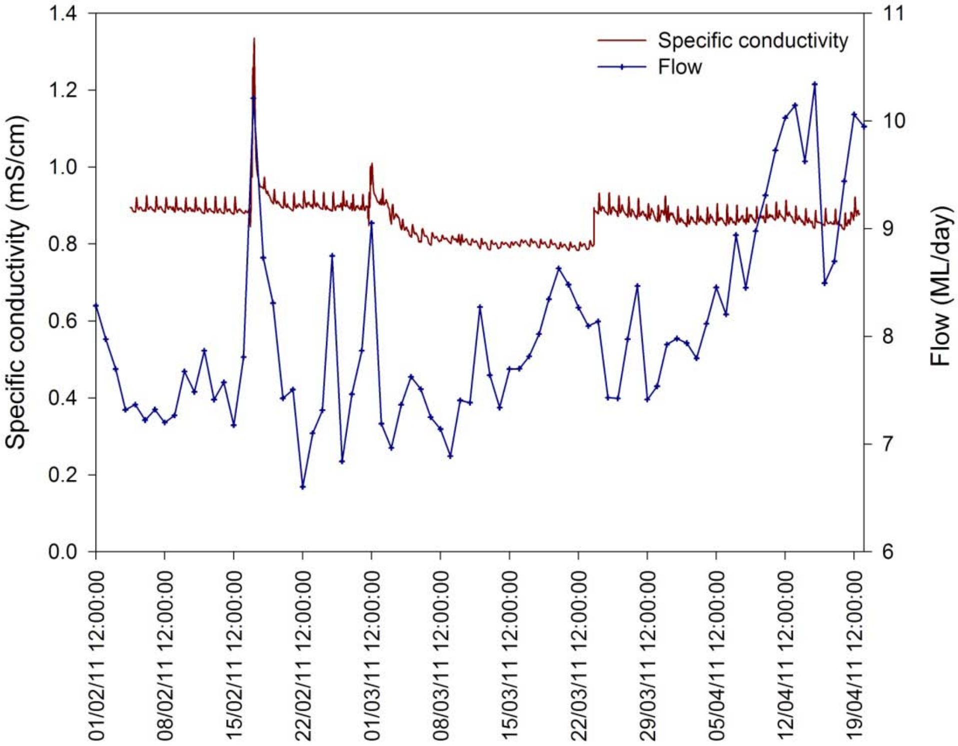

Figure 7 Specific conductivity monitored over the study period at the lower site on Lennard Brook.

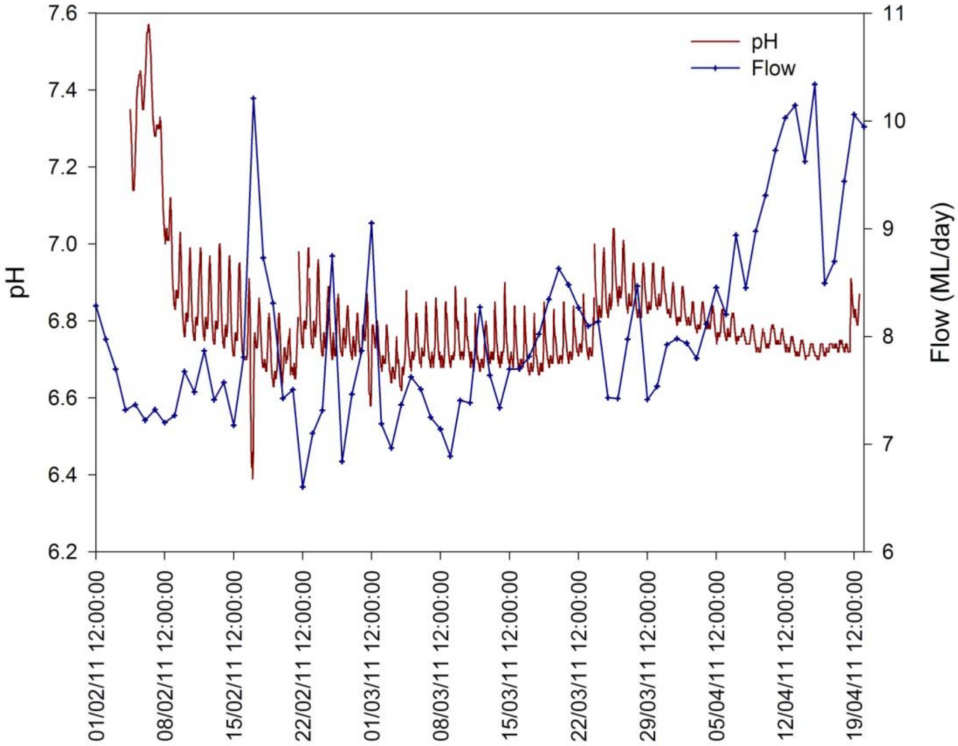

Figure 8 pH monitored over the study period at the lower site on Lennard Brook.

Appendix D — Photo points

1. Bridge looking upstream

2. Right bank looking downstream

February

March

April

Figure 9 Photo points 1 and 2 taken at the upper assessment site located on the upper reach of Lennard Brook, taken near the bridge.

3. Top of site looking downstream

February

March

April

Figure 10 Photo point 3 taken at the upper assessment site located on the upper reach of Lennard Brook, taken at the top of the site.

1. Top of site looking downstream

2. Top of site looking downstream

February

March

April

Figure 11 Photo points 1 and 2 taken at the lower assessment site located on the lower reach of Lennard Brook, taken at the top of the site.

3. Top of site looking downstream

February

March

April

Figure 12 Photo point 3 taken at the lower assessment site located on the lower reach of Lennard Brook, taken at the top of the site.

Appendix E — Strategic response during low flows

Response strategy for breach of low-flow trigger in the Lennard Brook

During low-flow periods (typically December to April) flow data should be monitored weekly to detect whether flows are below the low-flow trigger value of 6.6 ML/day for two consecutive days. This currently requires weekly downloading of data from the Molecap Hill gauging station (617165, non-telemetered site).

When the low-flow trigger is breached, regional staff are required to monitor dissolved oxygen in predetermined areas (outlined in Table 2), following the monitoring protocols outlined below, and collect additional information (Table 3) to be used for interpretation.

Monitoring is designed to be a rapid, cost-efficient approach to track dissolved oxygen concentrations and to elicit a more comprehensive response only if levels fall below 5 mg/L. Subsequent action is to be determined by a meeting of staff from the region and the Water Allocation and Water Science branches.

The low-flow trigger may be revised in future based on data collected on the relationship between the daily flow (ML) and dissolved oxygen.

Table 2 Assessment sites for dissolved oxygen monitoring.

Monitoring site	Depth profile locations	Coordinates	Access
Lower assessment site L1782 Brand Highway, Gingin.	Depth profile in deepest section of the brook.	31.3861°S 115.9091°E	Accessed by track located off Cockram Road (opposite Lennards Road). Contact landholder for access: Inghams Chicken (farm 2) 9575 1218
Upper assessment site L3311 Lennards Road, Lennard Brook.	Depth profile in deepest section of the brook.	31.3816°S 115.9692°E	Contact landholder for access: Jason Halliday 0409 978 040

Dissolved oxygen monitoring protocol

Ideally the measurement of dissolved oxygen level should be over a 24-hour period to capture diurnal fluctuations; however, spot measurements can be used so long as the expected daily fluctuations are considered. Hence spot measurements should be conducted in the early morning or late afternoon (the former being most important if phytoplankton and/or macrophytes are abundant) to capture the minima dissolved oxygen concentrations.

If using a hand-held water quality probe, take depth profile measurements (surface to 10 cm above the substrate) at 10 cm intervals. Measure dissolved oxygen in at least in two different locations within each site, preferably in the deepest areas.

If using a water quality data logger, ensure that the probe is placed at least 10 cm below the water's surface. Set the instrument to log data every 10 minutes. Ideally the equipment should be deployed in the morning and collected the next day after at least 25 hours have lapsed.

Refer to the field sampling guidelines (DoW 2009) for detailed information on how to take *in situ* dissolved oxygen measurements. Water Science staff can help set up the data logging equipment. Both hand-held water quality instruments and water quality data loggers can be borrowed from Water Science if required.

Table 3 Locations for assessment of system connectivity.

Site	**Measurement**	**Trigger and response**
Spratton Rd Lennards Rd Cockram Rd Brand Hwy assessment sites	Check water depth and note whether the Lennard Brook is flowing	If surface water is disconnected, check dissolved oxygen in the remaining waterbody. Record level of disconnection with photographs and note percent and type of aquatic habitat exposed. If dissolved oxygen levels are below 5 mg/L, convene a meeting with staff from the region and the Water Allocation and Water Science branches for subsequent actions.

Shortened forms

ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
CLFT	critical low-flow threshold
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EWR	environmental water requirement
SWIRC	South-west Index of River Condition

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.
Barrier assessment	The measurement and classification of barriers in rivers that prevent fish migration. Barriers can be physical such as dams and weirs, or chemical such as pollutants entering a waterway.
Baseflow	The component of streamflow supplied by groundwater discharge.
Climate change	A change of climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.
Discharge	The water that moves from the groundwater to the ground surface or above, such as a spring. This includes water that seeps onto the ground surface, evaporation from unsaturated soil, and water extracted from groundwater by plants (evapotranspiration) or engineering works (groundwater pumping).
Ecological health	Symptoms of an ecosystem's ability to perform nature's functions, affected by anthropogenic disturbance such as pollution and development of habitat and food sources.
Ecological values	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.
Flow regime	A description of the variation of the flow rate over time.
Refugia	Sections of a stream that provide habitat and sufficient water quality and quantity to preserve aquatic biota during low-flow periods.
Spring	A spring is where water naturally rises to and flows over the surface of land.
Surface water	Water flowing or held in streams, rivers and other wetlands on the surface of the landscape.
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)

Data sources

The maps in this publication were produced by the Department of Water with the intent that they be used as illustrations in this report *Assessment of low flow thresholds in maintaining ecological health of the Lennard Brook*. While the Department of Water 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 production of the maps:

Dataset Name	Custodian acronym	Metadata year
Hydrography, linear (hierarchy)	DOW	2007
Hydrography Linear (course scale) (Global Map Data Australia 1M)	GA	2001
Road centrelines	Landgate	2010
Western Australian towns	Landgate	2001
WA Coastline	DOW	2006
Water Information Network 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: GDA 94 (Geocentric Datum of Australia 1994)

Original ArcMap documents (*.mxd):
J:\gisprojects\Project\B_Series\B5047\000_related_tasks\010_GinginBk_LennardBk\mxds

References

Australian and New Zealand Environment and Conservation Council and Agriculture and Resources Management Council of Australia and New Zealand (ANZECC & ARMCANZ) 2000, *Australian and New Zealand guidelines for fresh and marine water quality*, available at: http://www.mincos.gov.au/publications/australian_and_new_zealand_guidelines_for_fresh_and_marine_water_quality [23 May 2011].

Beatty, SJ, Morgan, DL, Klunzinger, M & Lymbery, AJ 2010, *Aquatic macrofauna of Ellen Brook and the Brockman River: fresh water refuges in a salinised catchment,* report to the Ellen Brockman Integrated Catchment Group, Centre for Fish & Fisheries Research, Murdoch University, Western Australia.

Beatty, S & Morgan, D 2004, *Assessing the requirement for fishways on Gingin Brook,* report to the Gingin Land Conservation District Committee, Centre for Fish & Fisheries Research, Murdoch University, Western Australia.

Boulton, AJ & Lake, PS 1992, 'Benthic organic matter and detritivorous macroinvertebrates in two intermittent streams in south-eastern Australia', *Hydrobiologia*, vol. 241, pp. 107–118.

Bunn, SE & Arthington, AH 2002, 'Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity'. *Environmental Management,* vol. 30, pp. 492–507.

Chessman, BC 2003, 'New sensitivity grades for Australian river macroinvertebrates', *Marine and Freshwater Research*, vol. 54, pp. 95–103.

Commonwealth Scientific and Industrial Research Organisation (CSIRO) 2009, *Surface water yields in south-west Western Australia,* a report to the Australian Government from the CSIRO South-West Western Australia Sustainable Yields Project, CSIRO Water for a Healthy Country Flagship, Australia.

Department of Water 2011a, *Groundwater-surface water interaction along Gingin Brook Western Australia*, Department of Water, Government of Western Australia, Perth.

—2011b*, Gingin surface water allocation plan*, Department of Water, Government of Western Australia, Perth.

—2011c, *Gingin surface water allocation plan methods report*, Department of Water, Government of Western Australia, Perth.

—2009, *Field sampling guidelines: a guideline for field sampling for surface water quality monitoring programs*, Department of Water, Government of Western Australia, Perth.

Fairfull, S & Witheridge, G 2003, *Why do fish need to cross the road? Fish passage requirements for waterway crossings*, New South Wales Fisheries, Cronulla.

Galvin, L & Storer, T 2012, *Assessment of low-flow thresholds in maintaining the ecological health of the Gingin Brook,* Water Science Technical Series, report no. 41, Department of Water, Government of Western Australia, Perth.

Harvey, BC, Nakamoto, RJ & White, JL 2006, 'Reduced stream flow lowers dry-season growth of rainbow trout in a small stream', *Transactions of the American Fisheries Society,* vol. 135, pp. 998-1005.

Hay, J 2009, *Effects of low flow on dwarf galaxias and their habitat in the Wairau River*, Department of Conservation, Wellington, New Zealand.

Hunt, RJ & Christiansen, IH 2000, *Dissolved oxygen information kit*, a CRC Sugar technical publication, Cooperative Research Centre for Sustainable Sugar Production, Townsville.

Johnson, SL 2000, *Hydrogeological assessment of the perennial brooks on the Dandaragan Plateau*, Hydrogeology report HR180 (unpublished), Water and Rivers Commission, Perth.

Koehn, AH & O'Connor, WG 1990, *Biological information for management of native freshwater fish in Victoria,* Department of Conservation & Environment, Melbourne.

Lake, PS 2003, 'Ecological effects of perturbation by drought in flowing waters', *Freshwater Biology,* vol. 48, pp. 1161–1172.

McNeil, DG & Closs, GP 2007, 'Behavioural responses of a south-east Australian floodplain fish community to gradual hypoxia', *Freshwater Biology*, vol. 52, pp. 412–420.

Miller, SW, Wooster, D & Li, J 2007, 'Resistance and resilience of macroinvertebrates to irrigation water withdrawals', *Freshwater Biology*, vol. 52, pp. 2494–2510.

Morgan, D, Gill, H & Cole, N 2000, *The fish fauna of the Moore River catchment*, Murdoch Report to the Water and Rivers Commission.

Morgan, DL, Gill, HS & Potter, IC 1998, 'Distribution, identification and biology of freshwater fishes in south-western Australia', *Records of the Western Australian Museum Supplement*, vol. 56, pp. 1–97.

Norton, S & Storer, T (in press), *Decision tool: barrier prioritisation to aid the installation of fishways*, Water Science Technical series (in press), Department of Water, Perth.

Puckridge, JT, Sheldon, F, Walker, KF & Boulton, AJ 1998, 'Flow variability and the ecology of large rivers', *Marine and Freshwater Research*, vol. 49, pp. 55–72.

Reid, DJ, Quinn, GP, Lake, PS & Reich, P 2008, 'Terrestrial detritus supports the food webs in lowland intermittent streams of south-eastern Australia: a stable isotope study', *Freshwater Biology*, vol. 53, pp. 2036–2050.

Storer, T, White, G, Galvin, L, O'Neill K, van Looij, E & Kitsios, A 2011a, *The Framework for the Assessment of River and Wetland Health (FARWH) for flowing rivers of south-west Western Australia: project summary and results, final report,* Water Science Technical Series, report no. 39, Department of Water, Western Australia.

— 2011b, *The Framework for the Assessment of River and Wetland Health (FARWH) for flowing rivers of south-west Western Australia: method development, final report,* Water Science Technical Series, report no. 40, Department of Water, Western Australia.

Storey, AW & Davies, PM 2002, *Preliminary ecological water requirements for Gingin and Lennard brooks*, unpublished report by Aquatic Research Laboratory to Department of Water, Perth, Western Australia.

Walters, AW & Post, DM 2008, '*An experimental disturbance alters fish size structure but not food chain length in streams'*, *Ecology*, vol. 89, pp. 3261–3267.

White, G and Storer, T 2012, *Assessment of ecological health and environmental water provisions in the Harvey River (between Stirling Dam and Harvey Reservoir)*, February to May 2011, Water Science Technical Series, report no. 44, Department of Water, Western Australia.

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