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

Assessment of ecological health and environmental water provisions in the Harvey River

(between Stirling Dam and Harvey Reservoir) February to May 2011

Looking after all our water needs

Water *Science* technical series

Report no. WST 44
July 2012

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Contents

Figures

Tables

Summary

In late 2010 the environmental water provisions (flows provided to maintain environmental health) of a number of river systems in south-west Western Australia were temporarily reduced in response to reduced rainfall, with the winter of 2010 being the driest on record. The dry winter followed a prolonged period of drying climatic conditions and an associated reduction in water availability. For the Harvey River (between Stirling Dam and Harvey Reservoir) the agreed strategy for managing the water resource included a minimum release of 2 ML/day between December 2010 and May 2011.

In addition, given that water availability is likely to decline in the future (based on predictions from climate modelling), a potential management option may be to link release volumes to the volume of water flowing into the dam (i.e. mimicking non-regulated flows). This option is likely to result in releases from Stirling Dam stopping during dry periods, given that the Harvey River upstream of the dam has experienced periods of no flow during the past 10 years.

This study's primary objective was to assess whether the flow resulting from the agreed minimum release of 2 ML/day was sufficient to maintain the health of the aquatic ecosystem between the dam and the reservoir during the study period. The study also assessed how stopping water releases for a temporary period impacted on the health of the aquatic ecosystem.

Ecosystem health was assessed in two pools in the study reach between February and May 2011, with fish and crayfish community structure, water quality parameters and habitat availability used as indicators. Pool environments were selected for investigation as they represent likely refugia for biota during periods of low flow and drought.

The results of this study suggest that the minimum release of approximately 2 ML/day, which provided a mean flow of 2.4 ML/day (as recorded at Sunny Vale Farm gauge), was sufficient to maintain the health of the aquatic ecosystem in the Harvey River (between Stirling Dam and Harvey Reservoir) during the study period, based on the following: water quality was within reference condition guidelines; there was sufficient water to inundate the habitats present; and there was a viable population of the native fish and crayfish species identified in the reference condition (refer to Section 4.3 for reference condition).

Further, the results of the study suggest that stopping the release of water from Stirling Dam had a detrimental impact on the health of the aquatic ecosystem at the lower end of the reach, based on the following: dissolved oxygen declined rapidly and to levels below those identified as critical in the reference condition, riffle habitats were not maintained and the loss of inundation of in-stream habitats was likely to be detrimental to biota, given that the habitat was already affected by steeply incised banks and the lack of mid and under storey vegetation.

1 Introduction

This study assessed whether the agreed minimum release of environmental water for the Harvey River (between Stirling Dam and Harvey Reservoir), between December 2010 and March 2011, provided sufficient flows to maintain the health of the riverine ecosystem. The study also assessed the impact of stopping water releases for a temporary period on the health of the aquatic ecosystem.

1.1 Rationale

Water is released from dams in Western Australia for a range of purposes including maintaining the ecological health of waterways and associated ecosystem services (refer to Section 2.5). The volume of the environmental water provision (EWP) is specified in the water resource management operating strategy (WRMOS) for each dam, in most cases based on the recommendations of an ecological water requirement (EWR) study.

In late 2010 the EWPs of a number of river systems in south-west Western Australia (SWWA) were temporarily reduced in response to reduced rainfall, with the winter of 2010 being the driest on record (since comparable records began in 1900) (BoM 2010). The dry winter followed a prolonged period of drying climatic conditions and associated reduction in water availability: since the mid 1970s SWWA has experienced a decline in annual rainfall of approximately 10% (1976–2003 compared with 1925–75), corresponding with a reduction in streamflow of around 50% in the same period (IOCI 2005).

For the Harvey River (between Stirling Dam and Harvey Reservoir) it was agreed that between October 2010 and May 2011 the release of water from Stirling Dam would be 50% of the inflow into the dam, until inflow fell below 5 ML/day, after which 100% of the inflow would be released. The maximum number of days with no release (the ‘no-flow limit’) was set at 40 days, however this was revised in response to concerns about the potential ecological impacts of stopping flow in the river system; hence between December 2010 and May 2011 a minimum release of 2 ML/day was applied (refer to Section 2.3). This study’s primary purpose was to assess the health of the aquatic ecosystem under the minimum release volume (2 ML/day) to determine whether there was any detrimental impact on the riverine environment.

Water availability is likely to decline in the future (based on predictions from climate modelling which predicts the mean annual runoff in the Harvey region will reduce by between 7 and 40% in 2030 (CSIRO 2009)). This may lead to pressure to reduce EWPs. A potential management option may be to control releases based on the volume of water flowing into the dam (i.e. mimicking non-regulated flows). This is likely to result in releases from Stirling Dam ceasing, given that the Harvey River upstream of the dam has experienced no-flow periods during the past 10 years (WRM 2010). The secondary purpose of this study was to assess the health of the aquatic ecosystem under a ‘no-release’ scenario, to determine whether ecosystem health would be maintained (as would occur in a naturally seasonal system) or would decline in response to the lack of flow.

1.2 Objectives

The study’s objectives were:

- to assess whether the minimum release of 2 ML/day from Stirling Dam, agreed for the period between December 2010 and May 2011, was sufficient to maintain the health of the aquatic ecosystem between the dam and Harvey Reservoir during the study period
- to assess the impact of stopping the release of water from Stirling Dam on the health of the aquatic ecosystem between the dam and Harvey Reservoir.

2 Background

2.1 Study area

The Harvey River is located in SWWA approximately 100 km south of Perth (Figure 1 inset). The river originates on the Darling Plateau and flows into Stirling Dam. Water released from the dam flows north-west into the Harvey Reservoir. From the reservoir outlet, located near the base the Darling Scarp, the river flows north-west across the Swan coastal plain to the Peel-Harvey estuary (Figure 1). This study is focused on the reach between Stirling Dam and Harvey Reservoir (approximately 6.5 km).

The catchment of Stirling Dam is 251 km^2. According to data collated in 2000 for the National Land and Water Resources Audit (Department of Agriculture and Food, Land use in Western Australia v2 dataset), approximately 96% of the dam’s catchment is classified as conservation and natural resources, 3% is used for plantation forestry and the remainder is covered by cropping, grazing and water storage. The catchments of Harvey Reservoir that encompass the study reach are 64 km^2, approximately 83% of which is classified as conservation and natural resources. The remainder of the catchment is covered by grazing (14%) and cropping, plantation forestry and seasonal horticulture (approximately 3% in total) (Figure 1).

2.2 Management of the Harvey River water resource

Stirling Dam was built in 1948 and has a storage capacity of 57.4 GL. Water stored in the dam is used primarily for public drinking water and forms part of the Integrated Water Supply Scheme (IWSS) managed by the Water Corporation. Water is also transferred to Harvey Reservoir, and subsequently to the Harvey Irrigation District, which is managed by Harvey Water (the trading name for the South West Irrigation Management Cooperative Ltd). The Water Corporation controls the release of water from Stirling Dam for environmental purposes (the EWP) in accordance with the WRMOS developed by the Department of Water (DOW 2009a).

Details of the historic, current and future management arrangements for the Harvey River water resource can be found in the Wetland Research and Management report (WRM 2010) and Bennett (in prep.).

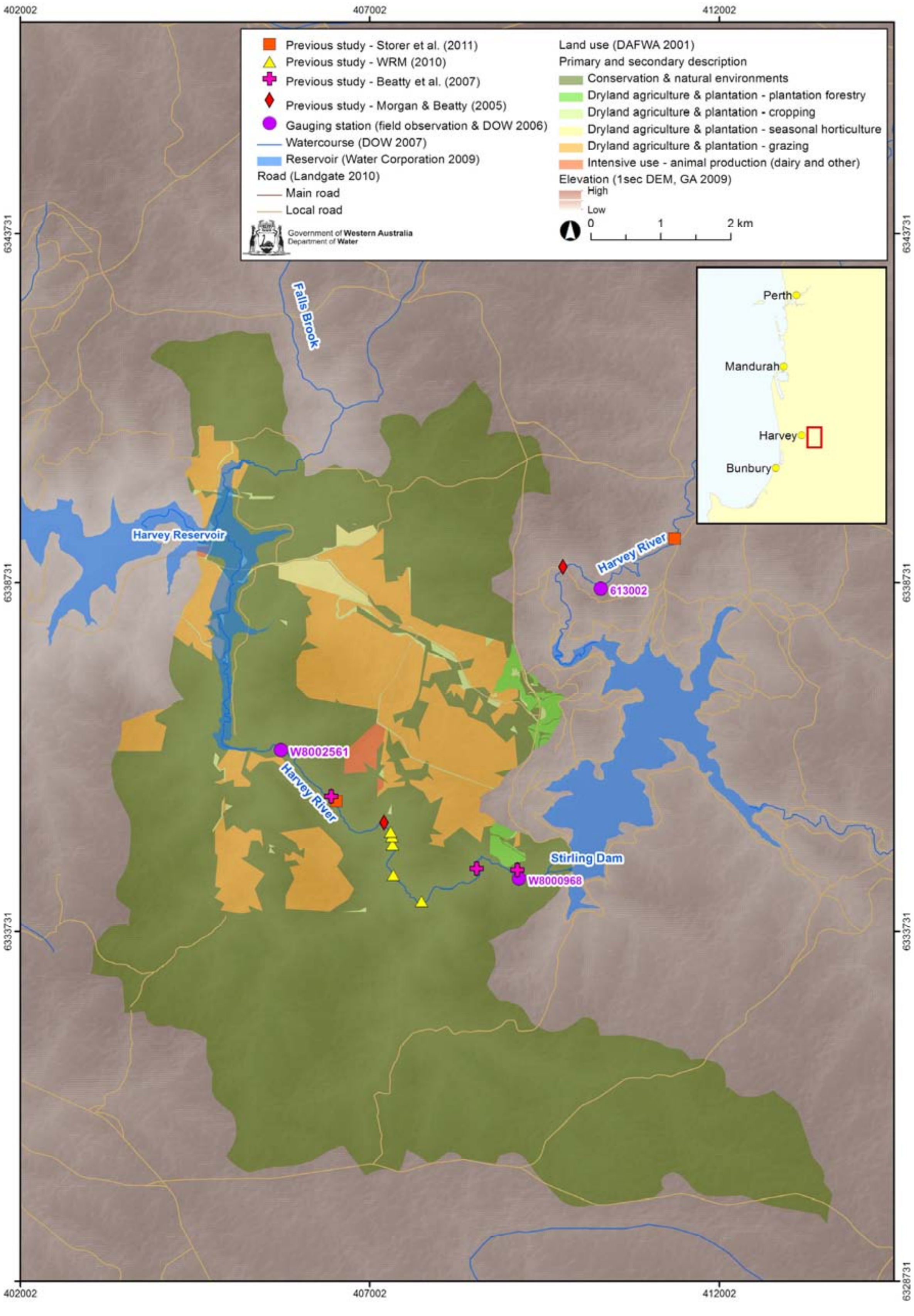


Figure 1 Harvey River catchment

2.3 Hydrological conditions

A number of gauging stations have been used to describe the hydrological condition of the Harvey River (Figure 1):

- Dingo Road gauge (613002, Department of Water) located upstream of Stirling Dam
- Stirling Below gauge (W8000968, Water Corporation) located approximately 0.8 km downstream from Stirling Dam
- Sunny Vale Farm gauge (W8002561, Water Corporation) located approximately 6.3 km downstream from Stirling Dam.

There is limited information about the Harvey River's natural flow regime before Stirling Dam was built. Streamtec (2001) estimated pre-European flows below the dam based on flows recorded at the Dingo Road gauge between 1984 and 2000 using a catchment area-rainfall model (Figure 2). The estimates suggest that the natural flow regime of the study reach was perennial and would have followed a seasonal pattern, with the highest mean monthly rainfall in August (12 700 ML/month) and the lowest in March (514 ML/month).

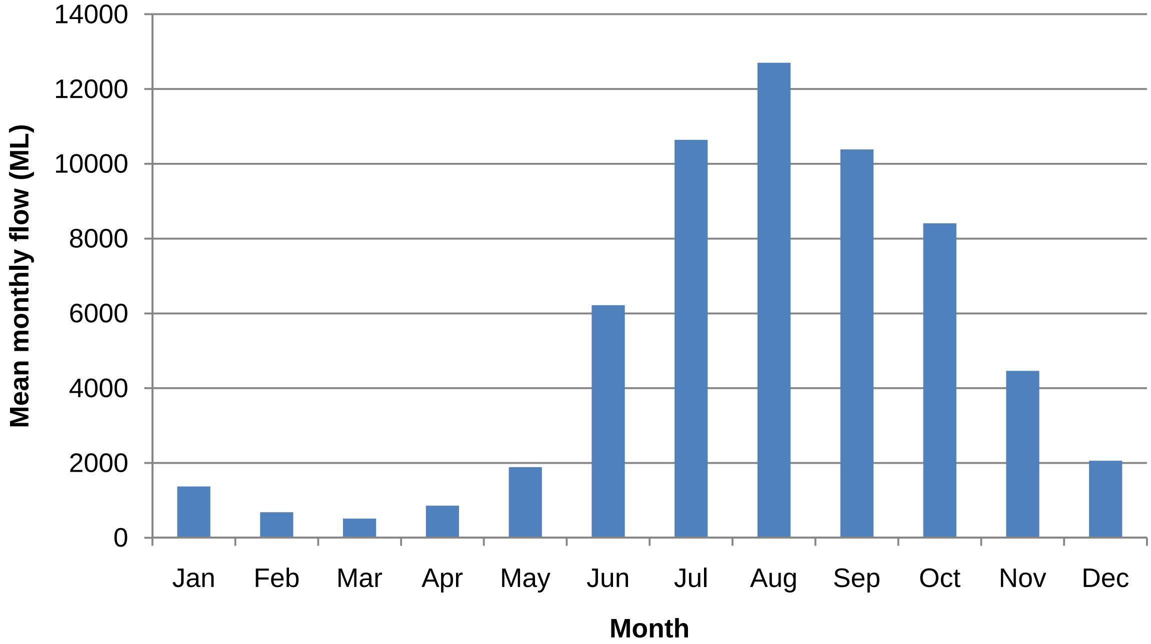


Figure 2 Modelled pre-European flow (ML/month) in the Harvey River downstream from Stirling Dam. Source: Streamtec (2001)

Between 1948 and 2001 water from Stirling Dam was used for irrigation purposes within the Harvey Irrigation District. During this period higher volumes of water were released from the dam during summer than winter to meet irrigation needs, leading to a reversal of the seasonal flow pattern compared with modelled pre-European flow (Figure 2) and contemporary flow at the Dingo Road gauge (Figure 3). Further, between 1979 and the late 1990s water was released periodically in high volume

(0.012–0.02 ML/sec, equivalent to 1037–1728 ML/day) for recreational canoeing; these 'white-water' events typically coincided with the summer irrigation releases but some events also occurred in winter (WEC et al. 1997, cited in Streamtec 2001).

Since 2001 water from Stirling Dam has been used for public water supply, initially for local supply and then for IWSS use from 2003. Water is transferred to the public water supply via pipes, hence the volume of water released from the dam during summer has reduced (Figure 3). Water is also transferred via the Harvey River to Harvey Reservoir before being used for irrigation purposes, hence there are still some large-volume releases during the summer months (resulting in the rise in the mean monthly flow in February to April for 2003 to 2008, Figure 3).

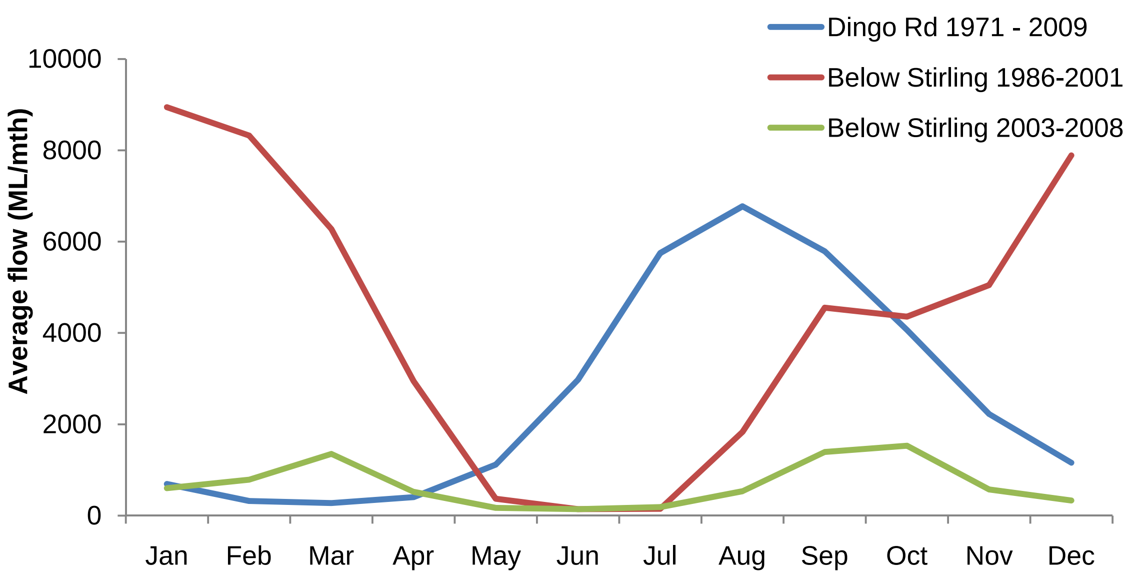


Figure 3 Mean monthly flow, in megalitres, recorded at Dingo Road gauge from 1971 to 2009, and Stirling Below gauge when water was primarily used for irrigation (1986–2001) and for public drinking water supply (2003–08). Note: 2002 was a period of transition between flow regimes, hence data from this year was excluded. Source: Bennett (in prep.)

The EWP was based on an EWR study by Streamtec (2001) and implemented in July 2003. A summary of the EWP's development is provided by Bennett (in prep.). The EWP has several components: continuous flow provisions for ecological needs (Table 1), additional short-duration flows for ecological needs, a channel forming and riparian vegetation flood event, and a fish migration component (DoW 2009a). Monitoring of compliance with the EWP specified in the WRMOS is assessed using flow data recorded at Sunny Vale Farm gauge (DoW 2009a).

Note that the mean flow recorded at Sunny Vale Farm between December 2003 and May 2010 was higher than the minimum flow provision specified in the WRMOS (Table 1). This may have been caused by various factors including releases of water for irrigation purposes, runoff, possible groundwater contribution and release-valve constraints at Stirling Dam (which has a minimum operating volume of 2 ML/day).

In response to the dry winter of 2010, the Department of Water and Water Corporation agreed on an approach to manage the Stirling Dam water resource, which was as follows:

- In September 2010 the flow provision (as recorded at Sunny Vale Farm gauge) was 50% of the ‘continuous flow provision’ specified in the WRMOS.
- Between October 2010 and May 2011 the flow provision was linked to inflow into the dam, as represented by flow recorded at the Dingo Road gauge (Figure 1). The flow requirement was 50% of inflow until inflow fell below 5 ML/day, after which 100% of inflow was to be released. The maximum number of days with no release (the ‘no-flow limit’) was set at 40 days, however this was revised in December 2010 in response to concerns about the potential ecological impacts of stopping flow in the river system.
- As such, between December 2010 and May 2011 a minimum release of 2 ML/day from Stirling Dam was applied (Table 1).

The gauging station to be used for compliance monitoring of the temporary release volumes was not specified. The dry-season response arrangement was described as a ‘release volume’ (i.e. a specific volume of water to be released from the dam), whereas the EWP defined in the WRMOS requires the release of sufficient water to provide specified ‘flow volumes’ at Sunny Vale Farm gauge. Given that the Stirling Below gauge is closer to the dam wall than the Sunny Vale Farm gauge, it provides a more accurate measure of release volumes from the dam. However, given that compliance monitoring for the EWP is undertaken at Sunny Vale Farm gauge (DoW 2009a), this gauge was also used for compliance monitoring for the temporary dry-season arrangements (WC 2011).

Table 1 Minimum EWP flow provision required at Sunny Vale Farm gauge (DoW 2009a), mean flow recorded at Sunny Vale Farm gauge December 2003 to May 2010, and the temporary minimum release volume for December 2010 to May 2011, in megalitres.

	Dec	**Jan**	**Feb**	**Mar**	**Apr**	**May**
EWP: minimum flow provision in ML/month	196	59	11	19	75	90
Minimum flow provision in ML/day	6.3	1.9	0.4	0.6	2.5	2.9
Mean flow Dec 2003–May 2010 in ML/month	388	230	314	368	418	207
Mean flow Dec 2003–May 2010 in ML/day	13	7	11	12	14	7
Dry season: minimum release in ML/month	62	62	56	62	60	62
Dry season: minimum release in ML/day	2	2	2	2	2	2

2.4 Social and economic values

The use of water from Stirling Dam for the IWSS represents both a social and an economic value, meeting the general public need for potable water, as well as supplying water for business and commercial use. The supply of water for irrigation purposes also represents an economic value.

There are three current licences for surface water abstraction at the downstream end of the study reach (Figure 4). These allow the abstraction of surface water via an in-stream pump up to a maximum entitlement of 10 000 KL/year per licence (Department of Water, Water Resource Licensing database). This water can be used for general stock and domestic use, orchards and wine grapes – hence providing both a social and an economic value.

2.5 Ecological values and ecosystem services

A number of studies have been conducted on the Harvey River (between Stirling Dam and Harvey Reservoir), summarised in Table 2. The results indicate that the study reach is in relatively good condition. A total of seven species of native fish and crayfish have been found, all of which are endemic to SWWA. The macroinvertebrate community has been found to be 'reasonably diverse' (Streamtec 2001). The upper section of the study reach is well vegetated, with a moderately dense upper storey of native tree species and a mixed shrub under storey (WRM 2010). Vegetation in the lower part of the reach (adjacent to Sunny Vale Farm) is less dense, with evidence of riparian vegetation being impacted by grazing and erosion associated with reduced vegetation cover and the high volumes of water released for recreational canoeing (WEC et al. 1997). In addition, WRM (2010) observed feeding platforms of the water rat, which is listed as a Priority 4 species (in need of monitoring) under the provisions of the *Wildlife Conservation Act 1950* (DEC 2010).

In addition to the ecological values observed during previous studies, it is important to acknowledge the ecosystem services provided by waterways, including provision of clean water (e.g. nutrient use by aquatic and riparian vegetation), production of food and fibre (e.g. maintenance of water quality to a level suitable for agricultural and industrial use), maintenance of soil fertility (e.g. through flood events), maintenance of liveable climates, control of pests (e.g. mosquito larvae eaten by fish), and provision of cultural, spiritual and intellectual experiences (Cork et al. 2001).

Table 2 Summary of ecological values of the Harvey River (between Stirling Dam and Harvey Reservoir) found during previous studies

Study	Summary of findings
Storer et al. (2011a)	Four native fish species were found at a site approximately half way between Stirling Dam and Harvey Reservoir: western minnow, western pygmy perch, nightfish and freshwater cobbler. Two native crayfish species were also found: gilgie and smooth marron. No non-native fish or crayfish were captured. A sample of macroinvertebrates comprised 14 taxa and an estimated total abundance of 658 organisms. Over half of the sample were midge larvae (Chironominae family), while a third were worms (Oligochaeta class). The remaining organisms included: mayfly nymphs (*Tasmanocoenis* sp.), caddisfly larvae (*Oecetis* sp.), dragonfly larvae (*Austrogomphus* sp.and *Anisoptera* spp.), pea clams (*Sphaeridae* spp.), diving beetle larvae (*Dytiscidae* spp.), a ribbon worm (*Nemertea* spp.) and a water mite (*Hydracarina* spp.). An assessment of the ecological health of the reach found that the aquatic biota, water quality and catchment disturbance were considered to be in 'largely unmodified condition'. The fringing zone vegetation was in 'slightly modified condition' while the physical form and hydrological change were 'moderately modified'.
WRM (2010)	Preliminary field reconnaissance found the river between Stirling Dam and Sunny Vale Farm to be in 'relatively good condition ecologically'. Riparian vegetation comprised a moderately dense overstorey of native tree species with a mixed shrub under storey. The reach included pool/riffle sequences with pools persisting over summer, rockbars/riffles and woody debris. There was some evidence of erosion towards Sunny Vale Farm, attributed to historic high releases for irrigation or white-water canoeing. During a no-release trial, conducted in May 2010, dissolved oxygen levels remained high (above the environmental threshold set in the study). Feeding platforms of the water rat were observed.
Beatty et al. (2007)	Four native fish species were found: western minnow, western pygmy perch, nightfish and freshwater cobbler. Two native crayfish species were found: gilgie and smooth marron. Two non-native species were also found: brown trout and redfin perch.
Beatty and Morgan (2005)	Three native fish species were found: western minnow, western pygmy perch and freshwater cobbler, along with two native crayfish species: gilgie and smooth marron. Two non-native species were also found: rainbow trout and redfin perch.
Creagh et al. (2003) cited in WRM (2010)	Diverse macroinvertebrate fauna were found, dominated by Insecta with Crustacea and Mollusca forming a minor part of the community. An abundance of western minnow were reported.

Study	Summary of findings
Streamtec (2001) including reporting of biota data from Streamtec (1999), Streamtec (1998) and WEC et al. (1997)	Macroinvertebrate fauna were found to be ‘reasonably diverse’, although biodiversity was lower immediately below Stirling Dam, compared with the mid and lower parts of the reach. Three native fish species were found: western minnow, western pygmy perch and freshwater cobbler. Three species of native crayfish were found: marron, giligie and koonac. Four non-native species were found: brown trout, rainbow trout, redfin perch and mosquitofish. Riparian vegetation condition was found to be good overall, although there were areas of riverbank where native under storey was sparse. Evidence of erosion and disturbance by cattle was noted. Water quality was assessed as being of ‘high biological quality’ with neutral pH, low salinity and high dissolved oxygen.

2.6 Flow-ecology relationships

Flow regime is recognised as a key driver of riverine ecosystem function (Puckridge et al. 1998; Bunn & Arthington 2002). Reduced flow or low flow (at the lower end of the hydrograph) can lead to a number of changes in the aquatic ecosystem including (from Rolls in prep., summarised by Galvin & Storer 2012):

- 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 differing species’ tolerances (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 can include an accumulation of organic matter (Boulton & Lake 1992) and changes in biotic community composition due to changes in allochthonous and autochthonous inputs (Reid et al. 2008: Walters & Post 2008).
- Restriction of the distribution (migration) of biota between habitats and river reaches (Bunn & Arthington 2002). Ecological consequences can include increased importance of refugia in maintaining biotic biodiversity. Hence, sustainability relies on maintaining a number of good quality pools as refugia.

Flows resulting from the release of 2 ML/day, as well as the release of no water, are at the lower end of the hydrograph compared with the mean monthly flow for December to May since the EWP was implemented in 2003 (Figure 3); as such, it is possible that some of the above changes in ecosystem function may have occurred during the study period.

3 Methods

3.1 Assessment approach

This study focused on assessing the ecological health of pool environments, given they represent likely refugia for biota during times of low flow and drought (Bond & Cottingham 2008; Robson et al. 2008). If the flow conditions have a detrimental impact on the refugia within a river system it implies that the non-refuge areas are also likely to be affected (e.g. under low-flow conditions a riffle habitat may be dry and therefore unable to sustain aquatic organisms, while the deep water in a pool is more likely to persist and therefore provide habitat for biota).

The monitoring for this study was conducted between February and May 2011, encompassing the final four months of the six-month period when the minimum release volume applied (refer Section 2.3).

3.2 Indicator selection

Reduced flow within a river system can lead to a number of changes in the aquatic environment that can affect ecosystem health (summarised in Section 2.6). To assess whether the health of the riverine ecosystem was affected by the periods of minimal release and no-release, the following indicators of ecosystem health were selected: biota (fish and crayfish), habitat and water quality (described below). These indicators encompass biological, physical and chemical elements of the aquatic environment; as such they form an integrated approach to assessing river health.

Aquatic biota are used as a key indicator of river health because damage to biota is often the end-point of environmental degradation (NWC 2007). For this study, fish and crayfish were chosen to represent the biota of the system for a number of reasons:

- they are mobile and therefore reflect conditions in an extended area of the river system (Harris 1995) (as compared with less mobile biota such as macroinvertebrates that reflect more localised conditions)
- they respond to changes in hydrology, such as moving into pools to seek refuge if flow reduces or ceases (Robson et al. 2008)
- they are sensitive to changes in water quality, physical habitat and other components of the aquatic ecosystem (Harris 1995) and knowledge of specific tolerances can infer fluctuations in these components that may not be detected through spot sampling (CEAH & ID&A 1997)
- they have a sufficiently long lifespan to indicate long-term impacts through population structure (e.g. the prescence of juveniles of a particular species can indicate the success of reproduction in the previous season(s)).

The availability and quality of habitat within a river system can affect the characteristics of the biotic community (Maddock 1999; Boulton & Brock 1999); as such, evaluating habitat is an important component of ecosystem health assessment (Maddock 1999). This indicator was included to determine quality and availability of habitat under minimal release and no-release conditions and also to provide a general understanding of the habitat conditions in the Harvey River (to assist with the interpretation of biotic data).

Water quality (i.e. the physical and chemical properties of water) is a component of the physical habitat of a river system and thus can affect the biotic community present (see ANZECC & ARMCANZ 2000b for a review of biotic tolerances). Water quality data can provide information about the localised habitat conditions and can also give an indication of catchment-scale processes placing pressure on the aquatic ecosystem (e.g. high levels of suspended sediment may suggest that vegetation has been cleared from the upstream catchment).

The observation of flow at a system scale was also undertaken; this was supplementary to the site-scale assessment of ecological health. The observations broadly indicate whether flow persisted along the length of the reach during the study period, and provide useful contextual information for interpreting the response of biota during low-flow conditions.

3.3 Reference condition

To assess ecosystem health a benchmark or reference is required against which observations can be compared. This ‘reference condition’ can be set at pristine health before any impact, or at a state with a certain degree of impact or change from historic form and function. The latter is a more pragmatic approach given that the health of most river systems in SWWA has undergone significant change due to anthropogenic pressure and recognises that some changes are outside of current control (e.g. climate change); it also reflects the need for ongoing allowances for competing values (e.g. social and economic values such as water supply). As the environmental condition associated with this type of reference is more achievable, it is therefore more useful for water resource management.

A pragmatic approach to defining reference condition was required for the Harvey River given that the system has undergone significant hydrological change (Section 2.3), is affected by climate change (CSIRO 2009) and has agricultural practices occurring in the catchment.

In lieu of relevant baseline data, a reference condition was compiled for each ecological health indicator used in this assessment by considering data from previous studies, data from river systems of similar form and function, expert knowledge of biological requirements and guidelines for aquatic ecosystem protection. This includes the protection of critical ecosystem services (e.g. nutrient cycling and mosquito control). Reference conditions for each indicator are described in Section 4.

3.4 Site selection

Two likely refugia pools were selected: one in the upper half of the study reach and one in the lower half. The sites chosen represent the best-available pool habitats (i.e. most likely to be refugia) that were accessible (Figure 4) (site coordinates are provided in Appendix A).

The upper pool site was located approximately 2.5 km downstream from Stirling Dam (Figure 4). The site comprised a large pool (approximately 40 m long, 15 m wide and 0.9 m deep) and a rocky riffle approximately 40 m long and 10 m wide (Figure 5). The site falls within a Crown reserve (i.e. land vested in the Western Australian government) forming a river corridor approximately 100 m wide. Both the Crown reserve and the adjacent private property are covered with remnant native vegetation. The site was well vegetated with marri and peppermint trees, with an under storey of tea tree bushes, rushes and sedges (Figure 6).

A large rocky cascade occurred approximately 0.1 km upstream from the upper site, comprising a series of pools and small waterfalls. Between the cascade and the site the river consisted of a sequence of pools and runs. The river system downstream from the site consisted of a pool, riffle and run sequence of at least 0.1 km long (and may have continued further but was inaccessible due to vegetation cover).

The lower pool site was located approximately 6.3 km downstream from Stirling Dam, immediately downstream from the Sunny Vale Farm gauging station (Figure 4). The site consisted of a rocky riffle, a pool (approximately 12 m long, 10 m wide and 0.8 m deep), a run (approximately 30 m long, 4 m wide and 0.5 m deep) and a pool (approximately 20 m long, 10 m wide and 2 m deep) (Figure 7). The site falls within the Crown reserve (river corridor approximately 40 m wide), with private property on either side. To the north the land use is classified as 'minimal intervention use' and to the south as a mixture of grazing and 'minimal intervention use' (Department of Agriculture and Food, Land use in Western Australia v2 dataset). The upper storey of vegetation at the site was dominated by peppermint trees. The cover of mid storey and under storey was limited (less than 10% cover) and comprised tea tree, soap bush and blackberry bushes (mid storey) and rushes, sedges and exotic grasses (under storey) (Figure 8).

Downstream from the lower site the river system comprised a pool-run sequence of at least 0.2 km and may have continued further but was inaccessible due to vegetation cover. The riverine environment upstream from the site was not observed during the study.

For the assessment of system-scale flow, two observation points were chosen along the length of the study reach. Locations were selected where the track converges with the river allowing access to the riverbank (Figure 4) (other locations were not easily accessible due to the dense vegetation cover). Both observation points included a riffle and a pool (refer Appendix C for photos).

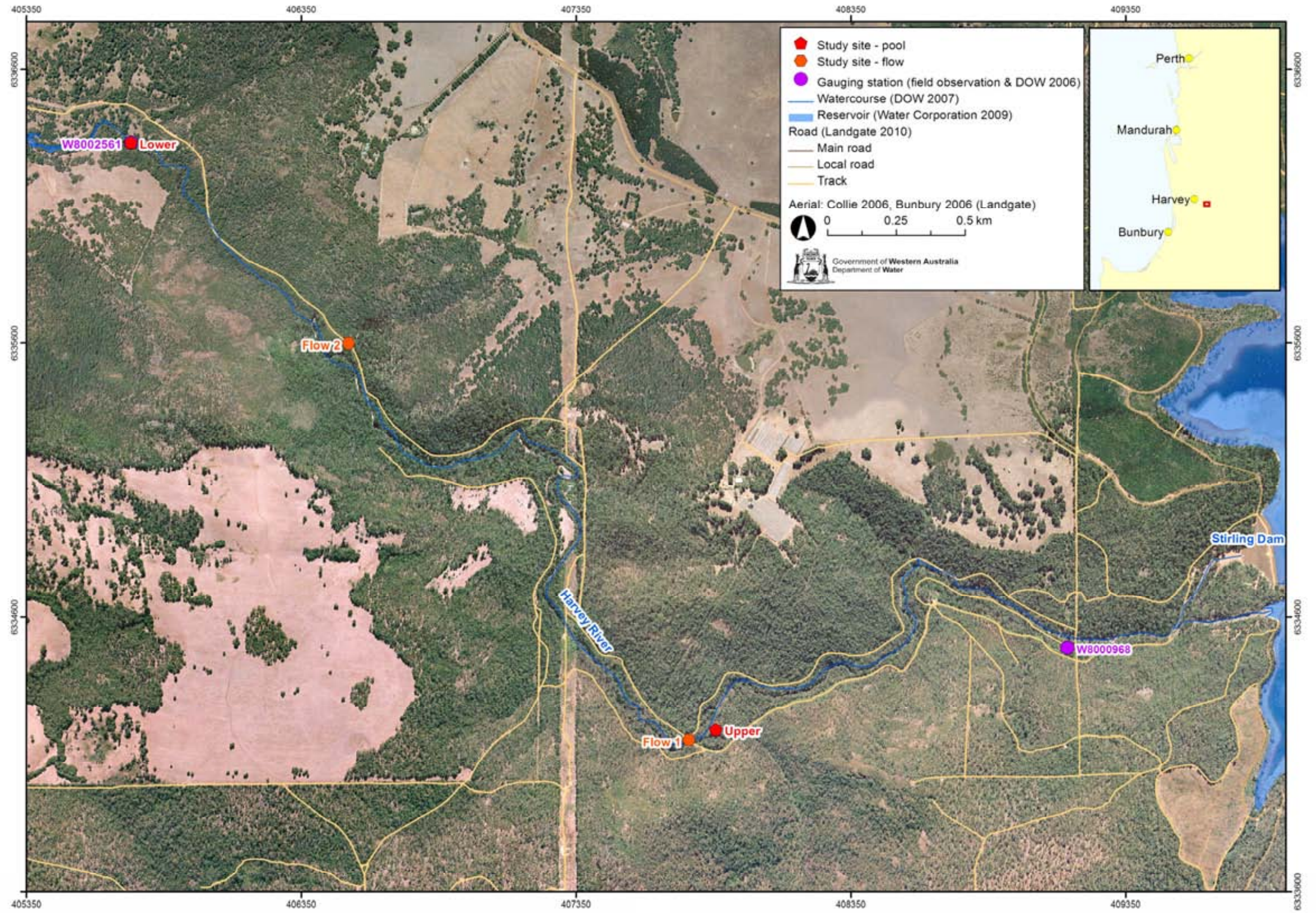


Figure 4 Study sites, stream gauging station and rainfall gauge

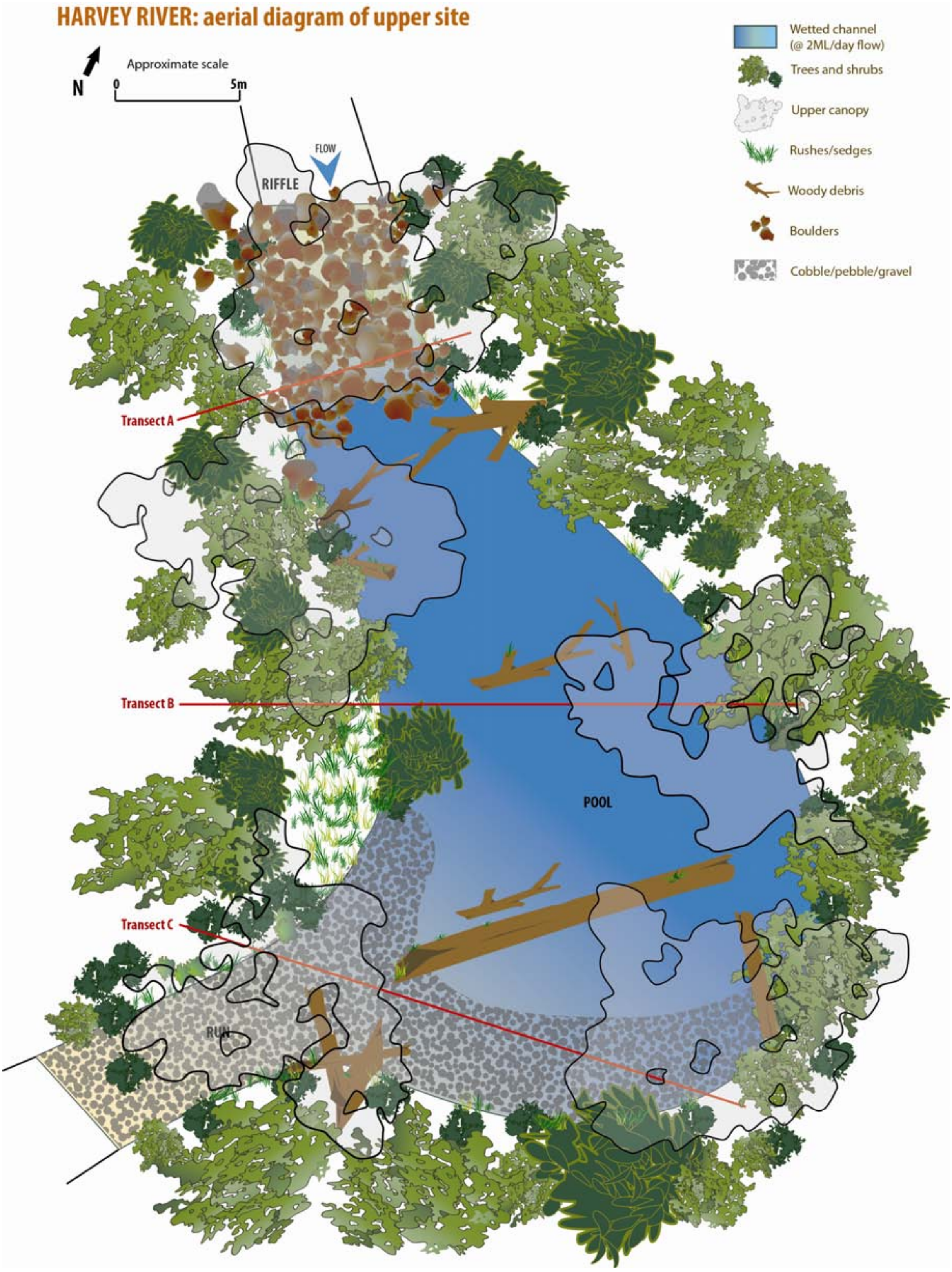


Figure 5   Aerial diagram of upper site

Figure 6 Vegetation at the upper site (pool)

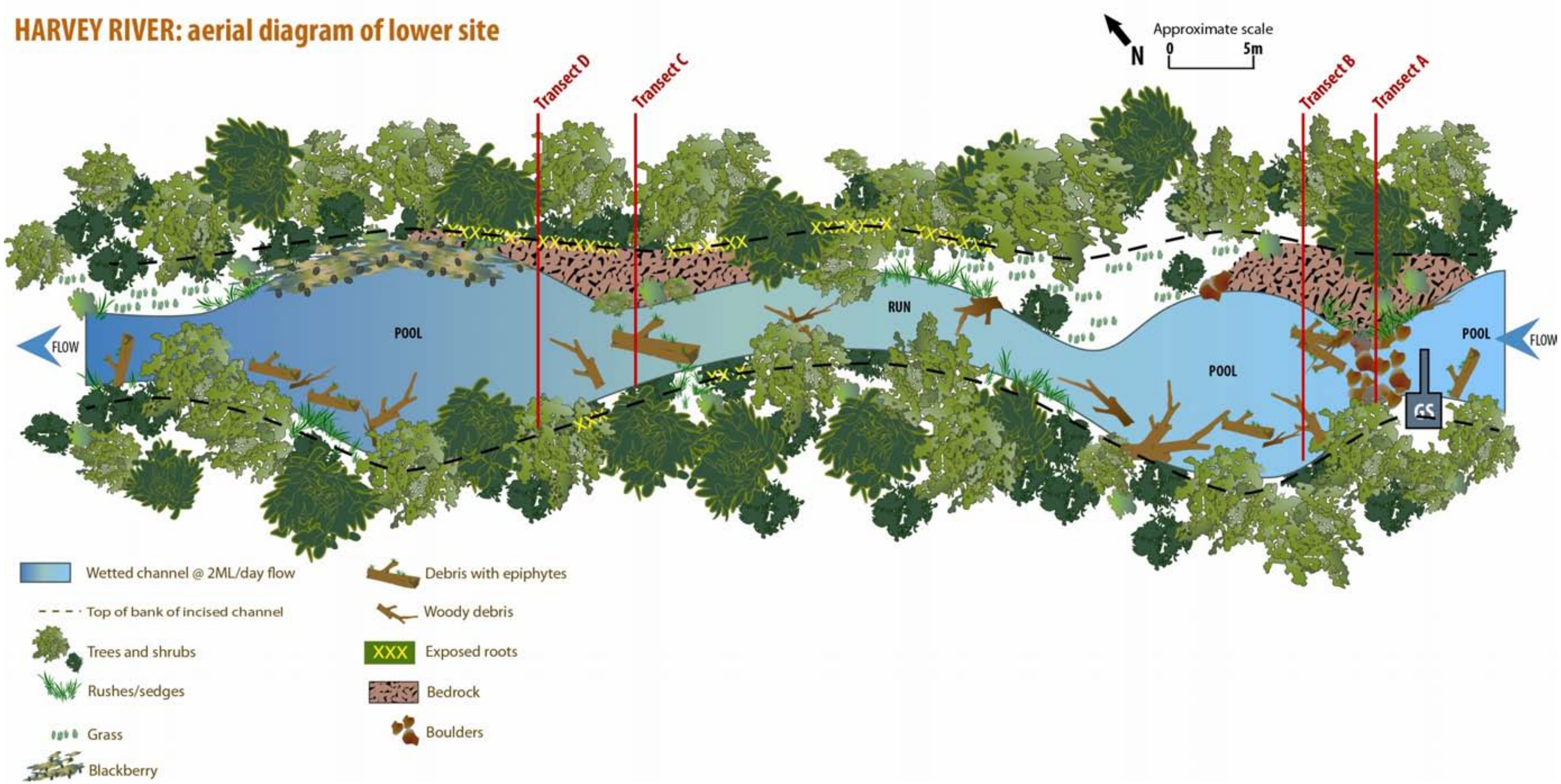


Figure 7 Aerial diagram of lower site

Figure 8 Vegetation at the lower site (pool)

3.5 Schedule for assessment under minimal release and no-release conditions

To assess ecological health under minimal release conditions, four sampling occasions were scheduled based on the understanding that releases would remain at, or close to, the agreed minimum level throughout the study period. Sampling was scheduled for 7 to 14 February (before the no-release trial) and at monthly intervals thereafter: 14 to 15 March, 11 to 12 April and 9 to 10 May (Table 3).

To assess ecological health under no-release conditions, a no-release trial was planned for February 2011. Water releases from Stirling Dam were stopped on the morning of 15 February and recommenced on 20 February 2011. Sampling began on 7 February and continued until 25 February to provide data before, during and after the period of no-release (Table 3).

A second period of no-release conditions occurred between 9 and 12 April 2011 when releases were stopped to allow divers to inspect the intake structure at Stirling Dam. The sampling occasion scheduled for 11 to 12 April coincided with these inspection works, hence data collected during this period was representative of no-release, rather than minimal release, conditions (Table 3).

Table 3 Key dates for changes to water releases and sampling occasions scheduled for this study

Period	Date	Activity	Sampling
Minimal release	7 February	Study began	7–25 February
No-release trial	15 February	Water release stopped	
	20 February	Water release started	
Minimal release			14–15 March
Inspection works	9 April	Water release stopped	11–12 April
	12 April	Water release started	
Minimal release	10 May	Study ended	9–10 May

3.6 Hydrological assessment of the study reach

Flow data were obtained from Sunny Vale Farm gauge. Given that compliance monitoring for the EWP is undertaken at this gauge (DoW 2009a), and that the gauging station for compliance monitoring of the temporary dry-season release volumes was not specified, it was selected as the main location for the hydrological data for this study. As such, the ecological response to the minimal release and no-release conditions are reported in relation to the flow recorded at the Sunny Vale Farm gauge (which may include runoff and groundwater contribution as well as water actually released from the dam).

Flow data were also obtained from the Stirling Below gauge to provide contextual information about the response time between changes made to the release valve at the dam wall and changes in flow at the gauging stations.

Rainfall data were obtained from the Bureau of Meteorology gauge at Harvey (009812). This gauge is located at the base of the Darling Scarp approximately 10 km west of the study reach and thus may not be representative of rainfall in the catchment’s upland portion, but it is the nearest rainfall gauge to the study reach.

As introduced in Section 3.4, flow was assessed at the pool sites and at two additional observation points along the length of the system (Figure 4). During the no-release trial the pool sites were visited daily, and the observations points were visited two to three times. During the remainder of the study period (March to May 2011) the pool and observation points were visited once per month. The presence or absence of flow was observed and a photograph taken.

3.7 Ecological assessment of pools

Habitat

General habitat features at each site were observed during the initial sampling event (7 February 2011) including bed substrate materials, woody debris, macrophytes, bank vegetation and shading. Characteristics of the riparian vegetation were noted including the width of the riparian zone, the cover provided by each layer of vegetation and the presence of exotic species. The field observation sheets used (Appendix B) were developed by the Department of Water for the South-West Index of River Condition (SWIRC) assessment protocol (Storer et al. 2011b).

To quantify changes in habitat availability a number of transects were established at each site. The transect locations were selected to represent the different macro habitats available at each site. At the upper site three transects were established: at the riffle (transect A), the middle of the pool (transect B) and the end of the pool (transect C) (Figure 5). At the lower site four transects were marked: across the riffle (transect A), the middle of the shallower pool (transect B), the run (transect C) and the upstream end of the deeper pool (transect D) (Figure 7). The habitats occurring along each transect were described (e.g. bed substrate, macrophytes, woody debris, riparian vegetation) and the depth of water was measured at 0.5 m intervals along the length of the transect. A 'depth reference point' was selected for each transect and the depth of water was measured.

During subsequent sampling occasions measurements and observations were made at the transects. Water depth was measured at the pool reference points on all sampling occasions, and at the riffle reference point on 24 or 25 February and during the March, April and May sampling occasions. The water width at each transect was measured on one sampling occasion in February (varying dates at the upper site; 21 February at the lower site) and monthly for the remainder of the study period. Changes to the habitat occurring along the transects (e.g. inundation of banks and draping vegetation) were observed during the March, April and May sampling events.

Water quality

Dissolved oxygen (mg/L), turbidity (NTU), temperature (°C), specific conductivity (µS/cm) and pH data were collected at the following time intervals:

- Continuous measurements were collected between 7 February and 14 April at the upper site (data collection ceased before the end of the study due to equipment failure), and between 7 February and 10 May at the lower site, using a Manta2 multi-parameter water quality probe.
- Spot measurements were taken at both sites on 8 and 10 February, daily between 15 and 25 February and once per month between March and May, using a Hydrolab Quanta multi-parameter water quality probe. These measurements were taken to calibrate logged data and examine spatial differences within each site.
- A grab sample was taken at each site on 15 February for analysis of the biochemical oxygen demand.

The collection method, location and time interval for each parameter is summarised in Table 4.

Table 4 Water quality parameters measured, data collection methods and collection frequency

Collection method and location	Frequency	Date(s)	Dissolved oxygen	Turbidity	Temperature	Specific conductivity	pH	Biochemical oxygen demand
Manta2 multiprobe: • at upstream end of pool • suspended horizontally in water column approx 0.1 m below the surface.	Continuous (10-minute intervals)	Upper site: 7 Feb – 14 April 2011 Lower site: 7 Feb – 10 May 2011.	✓	✓	✓	✓	✓	
Hydrolab Quanta readings taken: • at multiple locations in pool • in accordance with DoW guidelines (DoW 2009b).	Once per month	8 & 10 Feb, daily 15–25 Feb, 18 Mar, 11 Apr, 9 May 2011.	✓		✓	✓	✓	
Grab sample taken: • in pool 0.3 m above sediment surface • in accordance with DoW guidelines (DoW 2009b). *Sample analysed by National Measurement Institute laboratory*	Once during study	15 Feb 2011						✓

Fish and crayfish

Fish and crayfish sampling was conducted using a combination of fyke nets, large box traps and small box traps (Figures 9 and 10). The dimensions and deployment conditions are summarised in Table 5.

Figure 9 Fyke net (deployed at the upland pool site)

Figure 10 Box traps (large and small size)

Table 5 Nets and traps used for fish and crayfish sampling

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

Deployment ranged from 24 to 72 hours (Table 6), with nets being emptied every 24 hours during the 72-hour deployments. All fish and crayfish collected were identified to species and the following information was recorded: abundance, direction of movement (upstream or downstream), size class (see categories in field sheets, Appendix B), visual reproductive condition (including presence of berried or gravid females, nuptial colours, reddened vents, conspicuous urogenital papillae) and any conspicuous signs of declining fish condition (presence of ectoparasites, disease, physical injury or behavioural symptoms of stress, such as moribund or lethargic individuals). All native fish and crayfish were returned live to the water; exotic species were euthanised.

Table 6 Net and trap deployment schedule for fish and crayfish sampling at the upper and lower sites

Period	Deployment
Before the no-release trial 7–14 February	8–9 February: traps and fyke nets for 24 hrs
	9–10 February: fyke nets only for 24 hrs
No-release trial 15–21 February	14–15 February: traps and fyke nets for 24 hrs
	15–18 February: fyke nets only for 72 hrs
Recovery period 21 February to 5 March	21–22 February: traps and fyke nets for 24 hrs
	22–25 February: fyke nets only for 72 hrs
Minimal release period 5 March to 10 May	14–15 March, 11–12 April, 9–10 May: traps and fykes for 24 hrs

Contextual environmental conditions

At each pool site observations about a range of environmental conditions were made during the initial sampling event (7 February) including physical form and catchment disturbance (refer field observation sheets, Appendix B). The data collected provided contextual information to assist with the interpretation of the fish and crayfish, water quality and habitat data; as such the data have not been analysed directly and consequently have not been presented in this report.

4 Results

4.1 Hydrological conditions

According to data recorded at Sunny Vale Farm gauge, the mean daily flow during the study period (7 February to 10 May 2011) was 3.2 ML/day. Daily flow ranged from 0.3 ML/day on 21 February (the seventh day of the no-release trial) to 22 ML/day on 14 April (the day after releases resumed following the inspection works) (Figure 11).

Note that the flow volume recorded at Stirling Below gauge was lower than that recorded at the Sunny Vale Farm gauge (Figure 11). Given that the difference in flow persisted during periods of no rainfall (February and March 2011), this suggests that there may be a groundwater contribution to surface water between the two gauging stations, or that there is a difference in calibration between the gauges. It was beyond the scope of this study to clarify the cause for the difference in volumes recorded.

A delay was observed between the opening and closing of the release valve at Stirling Dam and the change in flow recorded at the two gauging stations. The length of the delay depended on the flow before closure of the valve, and on the volume of water released when opening the valve; as such, the following is indicative rather than absolute:

- At the Stirling Below gauge, flow was recorded as 1.5 ML/day on the day the release valve was closed (15 February); a reduction in flow was measured the following day, and it took approximately two days to reach the lowest flow volume. At the Sunny Vale Farm gauge, flow was recorded as 2.3 ML/day on 15 February; a reduction in flow was measured two days later (on 17 February) and flow continued to decline for a further four days (and may have continued if flow had not been resumed).
- After the valve was opened at the end of the no-release trial (on 20 February), an increase in flow was observed at the Stirling Below gauge the following day. At Sunny Vale Farm, a slight increase in flow was recorded two days after the release resumed, with a much greater increase in flow occurring on the third day (23 February).

Based on the data recorded at the Sunny Vale Farm gauge and rainfall data recorded at Harvey, flow appears to be influenced by rainfall in the catchment below Stirling Dam (Figure 11).

Flowing water was present throughout the reach during the periods when water was being released from the dam (as assessed at the two observation points and two pool sites, see Appendix C for photographs). During the two periods when water was not released from the dam (for this study and for inspection works) the flow of water throughout the reach ceased and the pools became disconnected (Appendix C).

Table 7 Minimum EWP flow provision required at Sunny Vale Farm gauge (DoW 2009a), temporary minimum release volume for December 2010 to May 2011, and mean flow recorded at Sunny Vale Farm gauge December 2010 to May 2011, in megalitres

		Dec	Jan	Feb	Mar	Apr	May
EWP in WRMOS	ML/month	196	59	11	19	75	90
	Expressed in ML/day	6.3	1.9	0.4	0.6	2.5	2.9
Dry season: minimum release volume	Expressed in ML/month	62	62	56	62	60	62
	ML/day	2	2	2	2	2	2
Flow at Sunny Vale Farm gauge	**Total ML/month**	**119**	**96**	**66**	**77**	**124**	**154**
	Mean flow ML/day	**3.8**	**3.1**	**2.4**	**2.5**	**4.1**	**5.0**

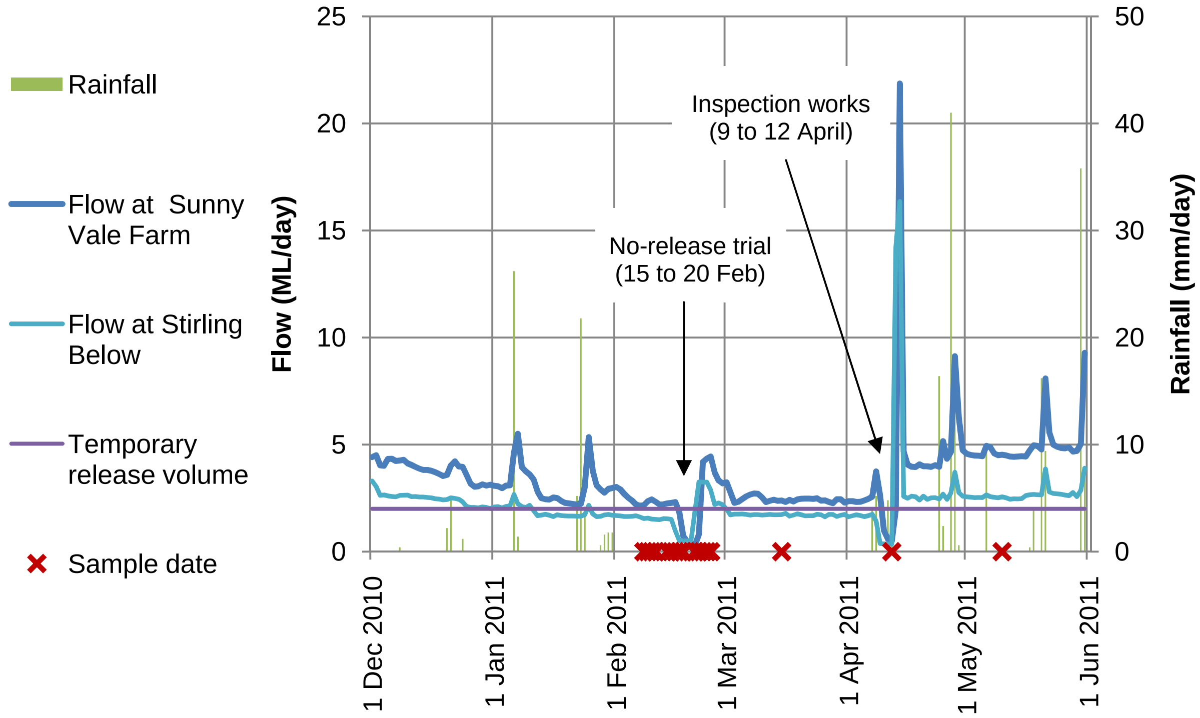


Figure 11 Daily rainfall recorded at Harvey (in millimetres), daily flow recorded at Sunny Vale Farm and Stirling Below gauges (in megalitres), temporary minimum release volume (in megalitres) and sample dates

4.2 Habitat

Although previous studies of the reach have described the riparian vegetation present, no data were available that was directly comparable to the data collected in this study (e.g. quantification of cover provided by riparian vegetation, description of in-stream habitat). In lieu of this, habitat health was assessed based on knowledge of habitat characteristics from observations made at similar river systems (regulated and non-regulated) in the region during work reported in Storer et al. (2011b).

The general structural complexity of habitat observed at each study site is illustrated in conceptual diagrams in Figures 12 and 15. The diagrams are based on specific conditions observed at the study sites, however they are generally representative of the broader conditions occurring in the reach.

Upper site

Within the upper site there was no indication of significant impact to habitat structure or availability. All structural layers of the riparian vegetation (upper, middle and under storey) were present and a diverse range of plant species were observed. Exotic plant species were not observed. There was a range of different in-stream habitats including variable flow velocity and water depth, woody debris, submerged macrophytes and epiphytes, and a mix of bed substrate materials (boulders, cobble, pebble, gravel and silt). Approximately 75% of the bank length was covered by draping vegetation. The whole length of the right bank (when facing downstream) was shaded by tree cover, while 75% of the left bank was shaded by tree cover. Approximately half of the length of each bank was shaded by overhanging shrubs and grasses (e.g. rushes, sedges). Both banks were concave in shape. The left bank was near vertical and tall (approximately 3 m high), while the right bank had a combination of steep and gently sloping areas and was approximately 1 m high (Figure 12).

Water width and depth at the upper site, as measured at the habitat transects and associated depth reference points (on various dates, refer to Section 3.7), fluctuated in response to the volume of flow recorded at Sunny Vale Farm gauge (Figures 13 and 14). At each depth reference point the water depth varied by 0.15 m during the course of the study. The water depth near the centre of the pool (transect B) ranged between 0.83 and 0.98 m; and between 0.06 and 0.18 m at the end of the pool (transect C). At the riffle reference point (transect A) the depth ranged between 0.07 and 0.22 m. Water width at the riffle (transect A) varied by 6 m, while at the pool transects water width varied by between 0.4 m (transect B) and 2.2 m (transect C).

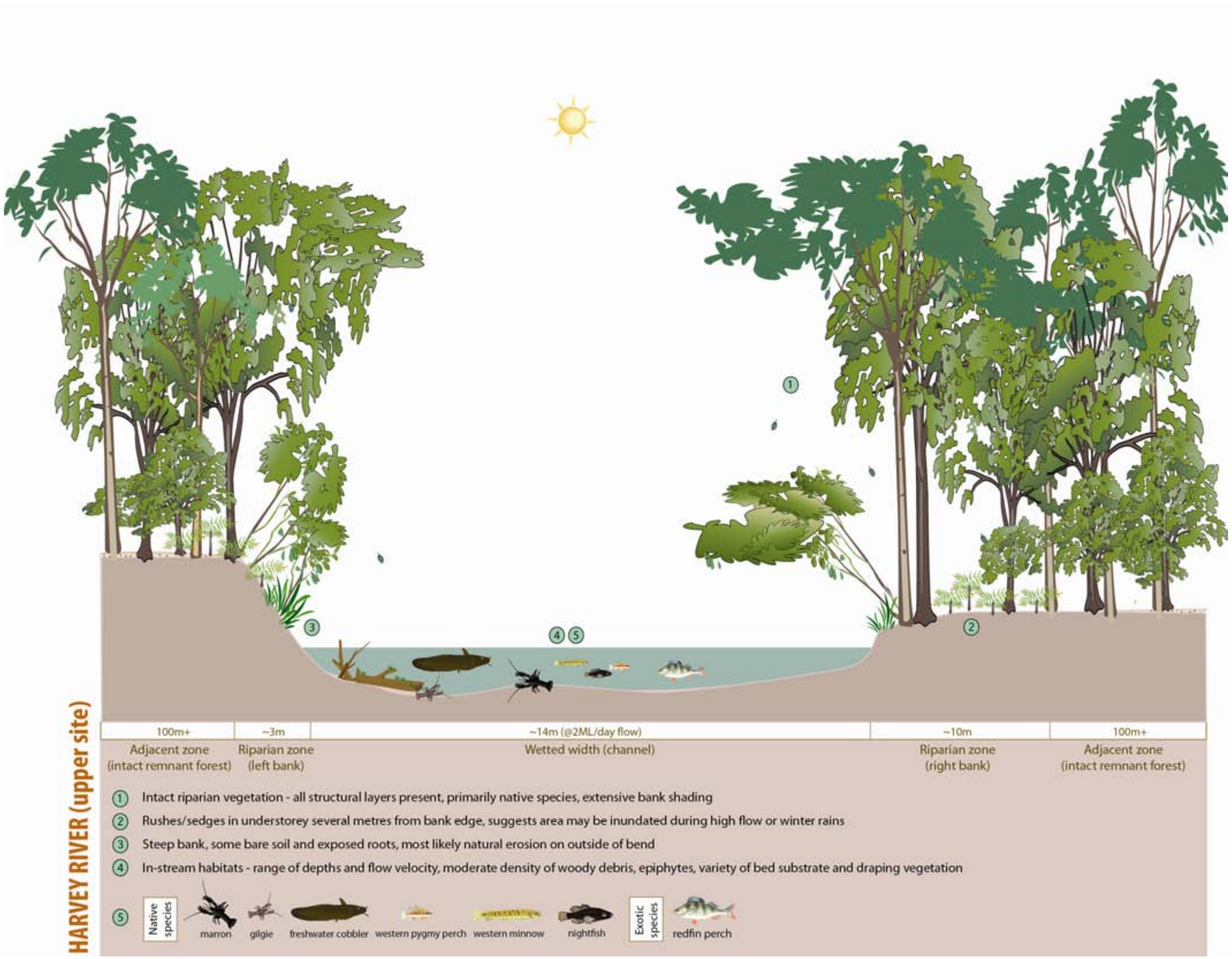


Figure 12 Conceptual diagram of the pool at the upper site

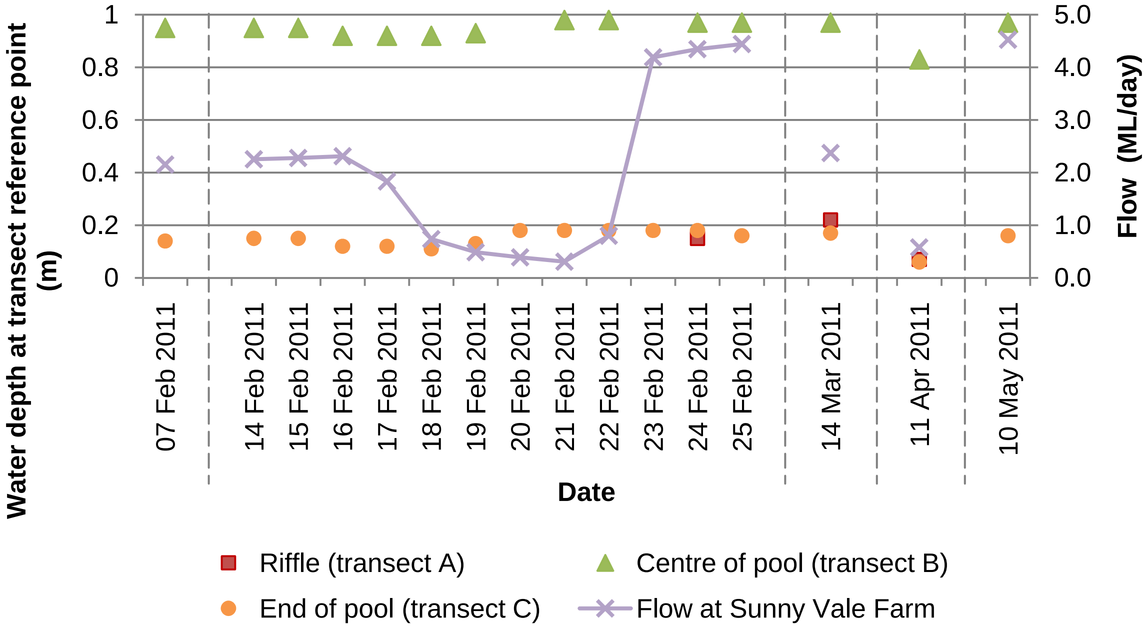


Figure 13 Water depth (metres) at reference points at the upper site and flow at Sunny Vale Farm gauge (megalitres/day)

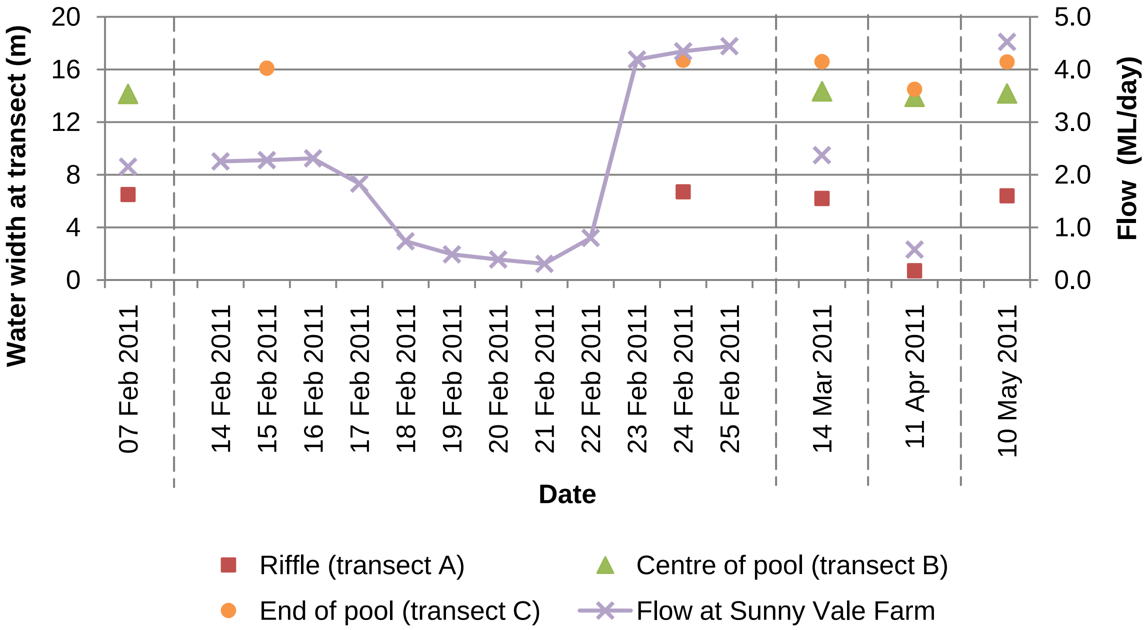


Figure 14 Water width (metres) at habitat transects at the upper site and flow at Sunny Vale Farm gauge (megalitres/day)

Changes in habitat availability, in response to changes in water width and depth, are summarised in Table 8. The inundation of rocks at the riffle transect was greatly reduced, resulting in the near complete loss of riffle habitat at the site. Other changes included the reduced inundation of flat edge habitat and shaded areas (e.g. those beneath draping vegetation), although these habitats were observed elsewhere at the site.

Table 8 Changes to habitat observed at the upper site on 11 April 2011 (during a no-release period)

Date	Transect	Observation
11 Apr 2011	Riffle	Majority of riffle dry (water width remaining 0.7 m and depth 0.07 m) Reduced inundation of sloping bank, roots and detritus on the right bank of the pool
	Middle of pool	Right bank: reduced inundation of most of sloping edge habitat and most of shaded region (shaded by draping vegetation, no longer inundated) Left bank: reduced inundation of vertical bank and some leaf litter, however this habitat is found elsewhere at the site
	End of pool	Right bank: Reduced inundation of flat edge habitat comprising rushes/sedges, gravel, pebbles and leaf litter Left bank: reduced inundation of flat edge habitat comprising silt/detritus, draping, although habitat occurs elsewhere at the site. Also reduced inundation of draping vegetation which comprises approximately 40% of the shaded area at the site

Lower site

At the lower site the structure and availability of habitat is considered to be impacted due to the limited cover of mid and under storey riparian vegetation (less than 10% cover provided by each storey) – which includes cover provided by exotic species of grasses and shrubs (blackberry). Accordingly, there was a loss of draping vegetation (5% of the bank length) and shade (while 100% of the bank length was covered by tree shade, only 2 to 5% of the bank length was shaded by shrubs and overhanging rushes/sedges). The left bank (when facing downstream) was near vertical and approximately 2 m tall with some undercutting observed. The right bank was also steep, being between 1.5 and 3 m tall but with areas of slumping and bedrock that provided gently sloping habitat at the water's edge. A range of different in-stream habitats were observed including variable flow velocity and depth, dense woody debris, and emergent and submerged macrophytes (Figure 15).

Water width and depth, as measured at the habitat transects and associated depth reference points (on various dates, refer to Section 3.7), also fluctuated with changes in flow (Figures 16 and 17). The water depth at the reference point on the riffle (transect A) ranged from 0.13 to 0.09 m (a difference of 0.04 m). The water depth in the upstream pool (transect B) varied by 0.21 m (from 0.90 to 0.69 m), as did the depth at the run (transect C) (ranging from 0.54 to 0.33 m). The water depth at the reference point for the downstream pool (transect D) fluctuated from 1.49 to 1.2 m (a difference of 0.29 m). The width of water at the riffle transect (A) altered by 5.2 m during the study period, while the water width at the upstream pool (transect B), run (transect C) and downstream pool (transect D) varied by 1.6 m, 2.5 m and 1 m respectively.

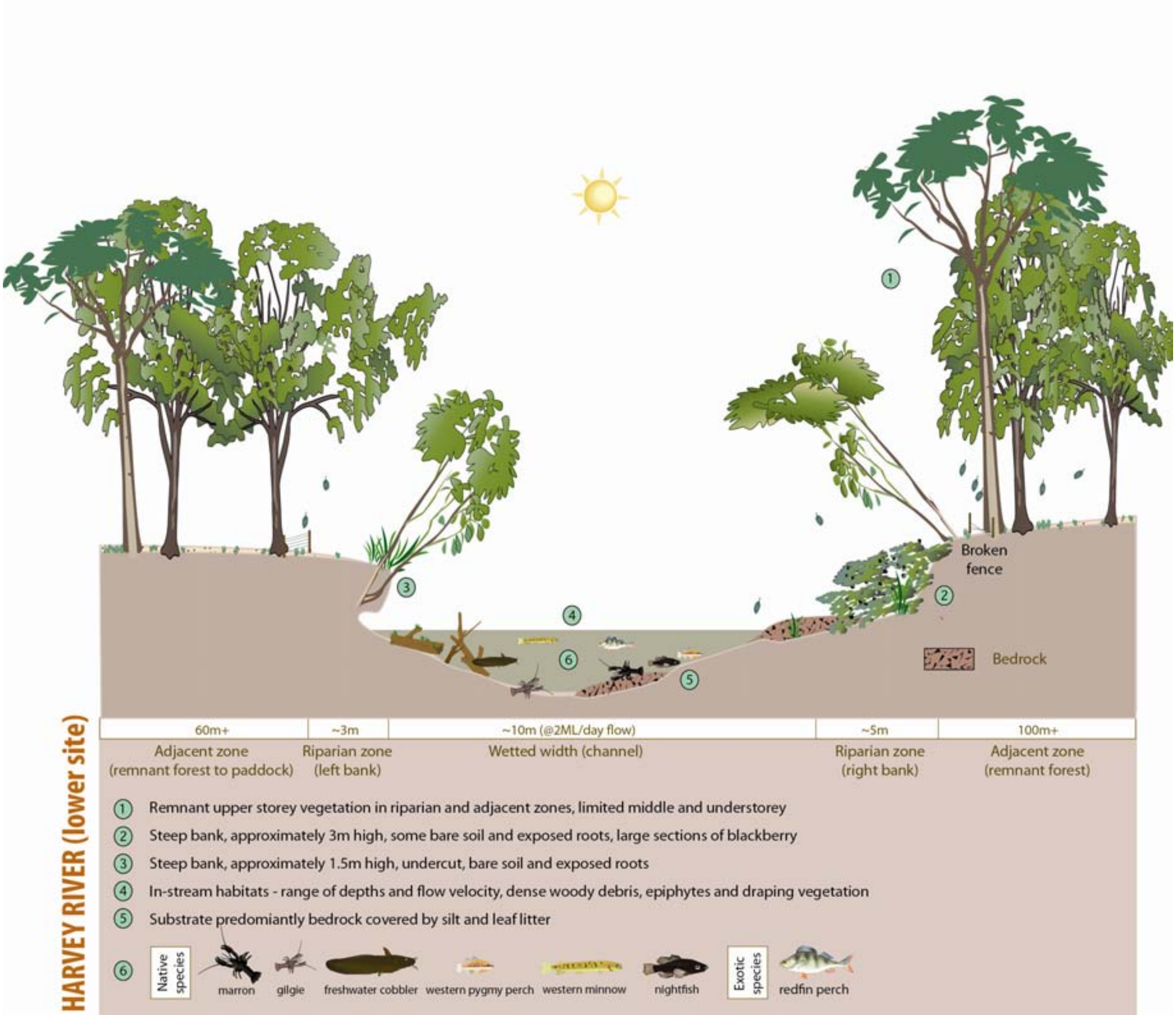


Figure 15 Conceptual diagram of the pool at the lower site

Changes in habitat availability, in response to changes in water width and depth, are summarised in Table 9. The inundation of rocks at the riffle transect (A) was greatly reduced, resulting in the near complete loss of riffle habitat at the site. Other changes included the reduced inundation of bedrock, macrophytes, undercut bank and draping vegetation, however these habitats were observed elsewhere at the site so the reduced inundation did not represent a complete loss of habitat.

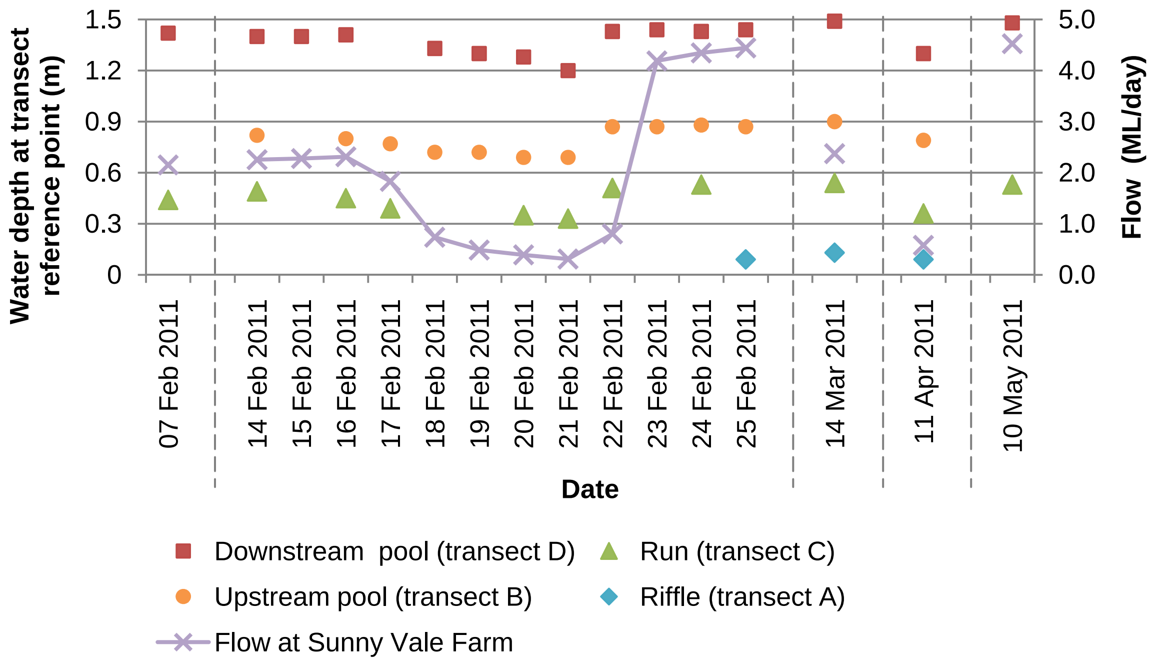


Figure 16 Water depth (metres) at reference points at the lower site and flow at Sunny Vale Farm gauge (megalitres/day)

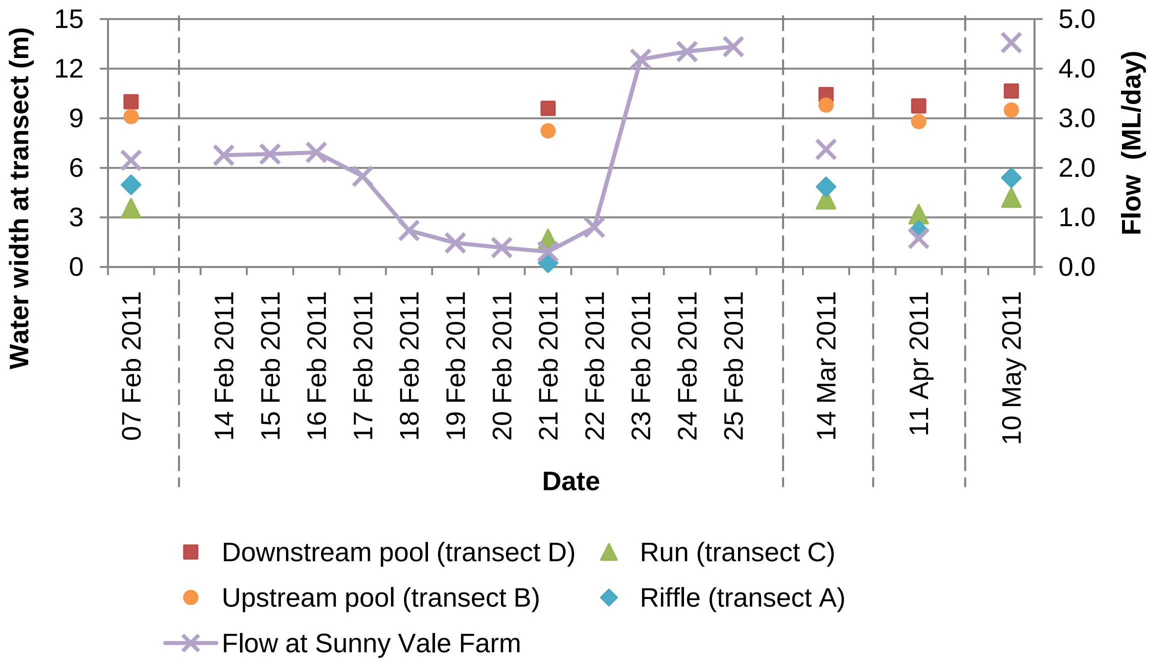


Figure 17 Water width (metres) at transects at the lower site and flow at Sunny Vale Farm gauge (megalitres/day)

Table 9 Changes to habitat observed at the lower site on 11 April 2011 (during a no-release period)

Date	Transect	Observation
11/4/2011	Riffle	Right bank: reduction of inundation of riffle habitat (boulders) Left bank: reduction of inundation of riffle habitat (boulders) and approximately 30% of the total length of overhanging vegetation at the site
	Manta pool	Right bank: reduction of inundation of 0.7 m rushes/sedges (100% of this habitat type) Left bank: reduction of inundation of 0.2 m of undercut bank (root mass and shade) (approximately 30% of this habitat lost)
	Run	Right bank: loss of inundation of 0.3 m bedrock (but habitat abundant throughout site) Left bank: loss of 0.6 m of edge habitat (large wood, detritus) (but habitat abundant throughout site)
	Fyke pool	Right bank: loss of inundation of silty sand/leaf litter and blackberry overhang Left bank: loss of inundation of 0.1 m of mud bank and overhanging bank (but habitat abundant elsewhere)

4.3 Water quality

Expected levels for the water quality parameters measured were compiled from literature about biotic tolerances, indicator thresholds used within river health assessments, and guideline values for protecting river ecosystems in SWWA (refer to Table 10 for reference guideline values and information sources).

Upper site

Results of the water quality monitoring, and reference condition values, are provided in Table 10 (and Appendix D), as well as summarised below:

- Dissolved oxygen was above the level thought to cause stress in aquatic fauna throughout the period of data collection (Koehn & O'Connor 1990; Waterwatch 2002).
- Biochemical oxygen demand was below detection level (5 mg/L) and is in keeping with the level typical for unpolluted waterways (DoE 2003).
- Specific conductivity was within the guideline values throughout the period of data collection (ANZECC/ARMCANZ 2000a).
- Based on the continuous data, pH was within the guideline values (ANZECC/ARMCANZ 2000a) throughout the period of data collection. Spot measurements of pH were within the guideline values on all sampling occasions except for 23, 24 and 25 February, when pH was between pH 7.9 and 8.5.
- The mean turbidity (calculated from continuous data collected starting 14 March) was within the guideline range (ANZECC/ARMCANZ 2000a). Some temporary increases in turbidity outside the guideline range occurred, primarily towards the end of the inspection works.
- The mean water temperature was within the 'normal' range for rivers in SWWA (DoE 2003). Water temperature fluctuated diurnally, with the maximum temperature exceeding the 'normal range' on a number of occasions in February and the minimum temperature being below the 'normal range' during the mornings of 8, 9 and 10 April (continuous data) and on the morning of 9 May (spot data).
- The mean diel (24-hour) fluctuations in temperature were less than the 4°C fluctuation thought to be detrimental to biota (Galvin et al. 2009; Storer et al. 2011b). A diel temperature range of greater than 4°C was recorded on just under half of the days of data collection.

Table 10 Water quality results for the upper pool site and reference condition values

Parameter	Data type[1]	Mean ± standard deviation	Range	Reference condition
Dissolved oxygen (mg/L)	C	8.0 ± 0.7	6.0–9.7	<2 mg/L is unable to support fish (Waterwatch 2002) and rates of respiration slow (Davies et al. 2004)
	S	7.1 ± 0.9	5.4–8.4	<5 mg/L causes stress to fauna (Koehn & O'Connor 1990); 5–6 mg/L are required for fish growth and activity (Waterwatch 2002)
Biochemical oxygen demand 5 day (total) (mg/L)	S		<5	<5 mg/L is typical of unpolluted waterways (DoE 2003)
Specific conductivity (µS/cm)	C	264.4 ± 3.6	258.0–279.5	120–300: ANZECC/ARMCANZ (2000a) trigger values for slightly disturbed river ecosystems in SWWA
	S	258.5 ± 6.4	248.0–270.0	
pH	C	6.9 ± 0.2	6.5–7.5	Lower limit 6.5; upper limit 8.0: ANZECC/ARMCANZ (2000a) trigger values for slightly disturbed river ecosystems in SWWA
	S	7.5 ± 0.5	6.9–8.5	
Turbidity (NTU)	C	1.2 ± 7.4	0–197.5	10–20: ANZECC/ARMCANZ (2000a) trigger values for slightly disturbed river ecosystems in SWWA
Temperature °C	C	21.4 ± 3.0	13.9–29.2	15–25°C is the typical temperature of SWWA rivers in summer (DoE 2003)
	S	22.3 ± 2.8	14.6–26.0	
Temperature °C (diel fluctuation)	C	3.8 ± 1.0	1.5–6.0	>4°C range likely to be detrimental to biota (indicator used by Galvin et al. 2009 and Storer et al. 2011b)

[1] Data type: C = continuous recording, S = spot sample

Lower site

Results of the water quality monitoring for the lower site are provided in Table 11. The data shows that water quality varied during different periods of the study: the mean and range of values for each period are given in Appendix D, and summarised below:

- Dissolved oxygen levels varied throughout the study period in response to the volume of water released from the dam, ranging from 0.5 to 10.5 mg/L. Periods of note are:
  - Before the no-release trial (7–14 February 2011, mean flow 2.3 ML/day as recorded at the Sunny Vale Farm gauge) the continuous data indicated that dissolved oxygen was greater than 5 mg/L – the threshold below which stress occurs in aquatic fauna (Koehn & O'Connor 1990). Spot measurements indicated that dissolved oxygen was below this threshold in some locations during this period.
  - During the no-release trial (15–21 February 2011, mean flow 1.2 ML/day) the mean dissolved oxygen (calculated for continuous data and for spot measurements) was less than the 5 mg/L threshold (Koehn & O'Connor 1990) but above the threshold for sustaining fish (2 mg/L, Waterwatch 2002).

    While the mean remained above the 2 mg/L threshold, the minimum values recorded did not. Based on the continuous data, the dissolved oxygen level decreased from 5.4 mg/L on 15 February to just below 2 mg/L on 19 February (i.e. decreased by 3 mg/L over four days). The dissolved oxygen level fluctuated around 2 mg/L on 19 February, then declined further and was below 2 mg/L for all of 20 February and until 8.20pm on 21 February. During this period the minimum value recorded was 0.5 mg/L.

    Spot readings of dissolved oxygen taken during the no-release trial (Appendix D) also decreased over time. Of the 12 locations where measurements were taken on 20 February, five had surface readings (0.1 m below the surface) of between 2 and 2.5 mg/L dissolved oxygen, and two had surface readings of greater than 3 mg/L (3.2 mg/L and 3.4 mg/L respectively). All readings taken below the water surface (i.e. >0.1 m deep) were less than 2 mg/L of dissolved oxygen. Spot readings were taken at 16 locations on 21 February. Of the surface readings, 10 were less than 2 mg/L and six were greater than 2 mg/L (the maximum value recorded was 2.93 mg/L). All readings taken below the water surface were less than 2 mg/L.
- Biochemical oxygen demand (as measured on 15 February 2011) was below detection level (5 mg/L) and is in keeping with the level typical for unpolluted waterways (DoE 2003).

- The mean specific conductivity for the whole study period (calculated for continuous data and for spot measurements) was within the guideline values (ANZECC/ARMCANZ 2000a). Periods of slightly increased specific conductivity can be seen in the continuous dataset (refer Appendix D): these appear to coincide with the periods when water was not released from the reservoir and also with a peak in turbidity in late April; however, the maximum value recorded was 328.1 µS/cm, which is only slightly higher than the upper guideline value (300 µS/cm) (ANZECC/ARMCANZ 2000a).
- The mean pH for the whole study period (calculated for continuous data and for spot measurements) was within the guideline values (ANZECC/ARMCANZ 2000a). Periods of slightly decreased pH can be seen in the continuous dataset (D): these appear to coincide with the periods when water was not released from the reservoir and also with a peak in turbidity in late April; however, the minimum value recorded was pH 6.3, which is only slightly lower than the lower guideline value (pH 6.5) (ANZECC/ARMCANZ 2000a). By contrast, the spot recordings of pH taken after the no-release trial ended (between 22 and 25 February 2011) were higher than at any other period during the study, with a mean of pH 8.2, which is just above the upper guideline value (pH 8.0).
- The mean turbidity recorded was above the guideline range (ANZECC/ARMCANZ 2000a), however the standard deviation indicates a high degree of variability in the values. For the majority of the study period the turbidity values were within the guideline range, although some short-term increases in turbidity occurred that were outside the guideline range.
- The mean temperature (calculated for continuous data and for spot measurements) was within the ‘normal’ range for rivers in SWWA (DoE 2003). Based on the continuous data the water temperature declined over the period of the study, and follows a similar pattern to the air temperature recorded at Harvey (BoM station 009812) (Appendix D).
- The mean diel (24-hour) fluctuations in temperature were less than the 4°C fluctuation thought to be detrimental to biota (Galvin et al. 2009; Storer et al. 2011b).

Note: during the no-release trial an oily substance was observed on the surface of the water at the lower site.

Table 11 Water quality results for the lower pool site and reference condition values

Parameter	Data type[1]	Mean ± standard deviation	Range	Reference condition
Dissolved oxygen (mg/L)	C	6.8 ± 1.8	0.5–10.4	<2 mg/L is unable to support fish (Waterwatch 2002) and rates of respiration slow (Davies et al. 2004) <5 mg/L causes stress to fauna (Koehn & O'Connor 1990); 5–6 mg/L are required for fish growth and activity (Waterwatch 2002)
	S	3.8 ± 2.1	0.9–9.5	
Biochemical oxygen demand 5 day (total) (mg/L)	S	<5		<5 mg/L is typical of unpolluted waterways (DoE 2003)
Specific conductivity (µS/cm)	C	280.3 ± 7.8	250.0–328.1	120–300: ANZECC/ARMCANZ (2000a) trigger values for slightly disturbed river ecosystems in SWWA
	S	0.3 ± 0	0.3	
pH	C	6.6 ± 0.1	6.3–6.8	Lower limit 6.5; upper limit 8.0: ANZECC/ARMCANZ (2000a) trigger values for slightly disturbed river ecosystems in SWWA
	S	6.9 ± 0.6	6.3–8.9	
Turbidity (NTU)	C	25.4 ± 117.2	7.5–2884.0	10–20: ANZECC/ARMCANZ (2000a) trigger values for slightly disturbed river ecosystems in SWWA
Temperature °C	C	18.8 ± 3.8	10.6–27.3	15–25°C is the typical temperature of SWWA rivers in summer (DoE 2003)
	S	21.6 ± 2.4	12.7–25.1	
Temperature °C (diel fluctuation)	C	2.5 ± 0.7	1.2–4.1	>4°C range likely to be detrimental to biota (indicator used by Galvin et al. 2009 and Storer et al. 2011b)

4.4 Fish and crayfish

Species richness

The reference condition for native fish and crayfish species richness for the lower site is generated from expectations based on species recorded in previous studies (refer Table 2, Section 2.5). These studies were conducted between 1997 and 2010, as such they reflect species richness under regulated flow conditions.

Note: the presence of exotic species is not included in the reference condition for sites, regardless of presence in previous studies, because the presence of exotic species represent a decline in system health.

At both sites the species of native fish and crayfish found matched the reference condition (Table 12).

Table 12 Fish and crayfish species found at the study sites, and reference condition

	Species	**Reference condition**	**Observed (at both sites)**
Native fish	Western minnow (*Galaxias occidentalis)*	✓	✓
	Western pygmy perch (*Edelia vittata*)	✓	✓
	Nightfish (*Bostockia porosa*)	✓	✓
	Freshwater cobbler (*Tandanus bostocki*)	✓	✓
Native crayfish	Smooth marron (*Cherax cainii*)	✓	✓
	Gilgie (*Cherax quinquecarinatus*)	✓	✓
Non-native fish	Redfin perch *(Perca fluviatilis*)		✓

Population structure

It was not possible to define a reference condition for the population structure of fish and crayfish in the Harvey River; instead the results were interpreted in the context of general population viability (e.g. presence of individuals in a range of size classes including ‘young of year’).

Upper site

At the upper site the mean abundance of fish and crayfish found in the fyke nets[1] was 30 ± 12 (Table 13). Small fluctuations in relative abundance between sampling events occurred, with the exception of 17 February (two days after the water releases ceased) when the total abundance was more than double that of the previous sampling occasions (Figure 18). The total increase was primarily due to western minnows increasing from a mean of five individuals in the previous samples to 30 on 17 February. A small increase in the abundance of nightfish was also seen.

The direction of movement of fish and crustaceans at the upper site is shown in Figure 19. Note: freshwater shrimp have been included in the direction results because they showed a marked response during the periods when water releases from the dam ceased. There was some variability in the proportion of individuals moving upstream and downstream on each sampling occasion, however the difference was minor. Aside from freshwater shrimp, the greatest movement of a species occurred on 17 February (two days after the water releases ceased) when a proportionally large number of western minnows were found to be moving upstream into the pool.

Marron, gilgie, western minnow and freshwater cobbler were found in the full range of size classes relevant to each species (Appendix E). Nightfish and western pygmy perch were found in a range of size classes, with the exception of the smallest (typically representing the ‘young of year’) (Appendix E). Redfin perch were found in a range of size classes but were more abundant in the ‘young of year’ size than in any other class (Appendix E).

Signs of reproduction (distended abdomen) were noted for nightfish during the March and April samples, and for western minnow in the May sample. There were no signs of stress or disease observed in the fish and crayfish found. An observation of high vigour was made regarding the fish and crayfish found on 18 February.

[1] To compare abundance data across all the sampling occasions, the data from the traps (used on some sampling occasions) have been excluded from these figures but is provided in Appendix D.

Table 13   Total abundance of fish and crayfish (collected in fyke nets) at the upper site

Date	9 Feb	10 Feb	15 Feb	16 Feb	17 Feb	18 Feb	22 Feb	23 Feb	24 Feb	25 Feb	15 Mar	12 Apr	10 May
Abundance	36	36	28	24	64	36	29	17	18	23	21	35	22

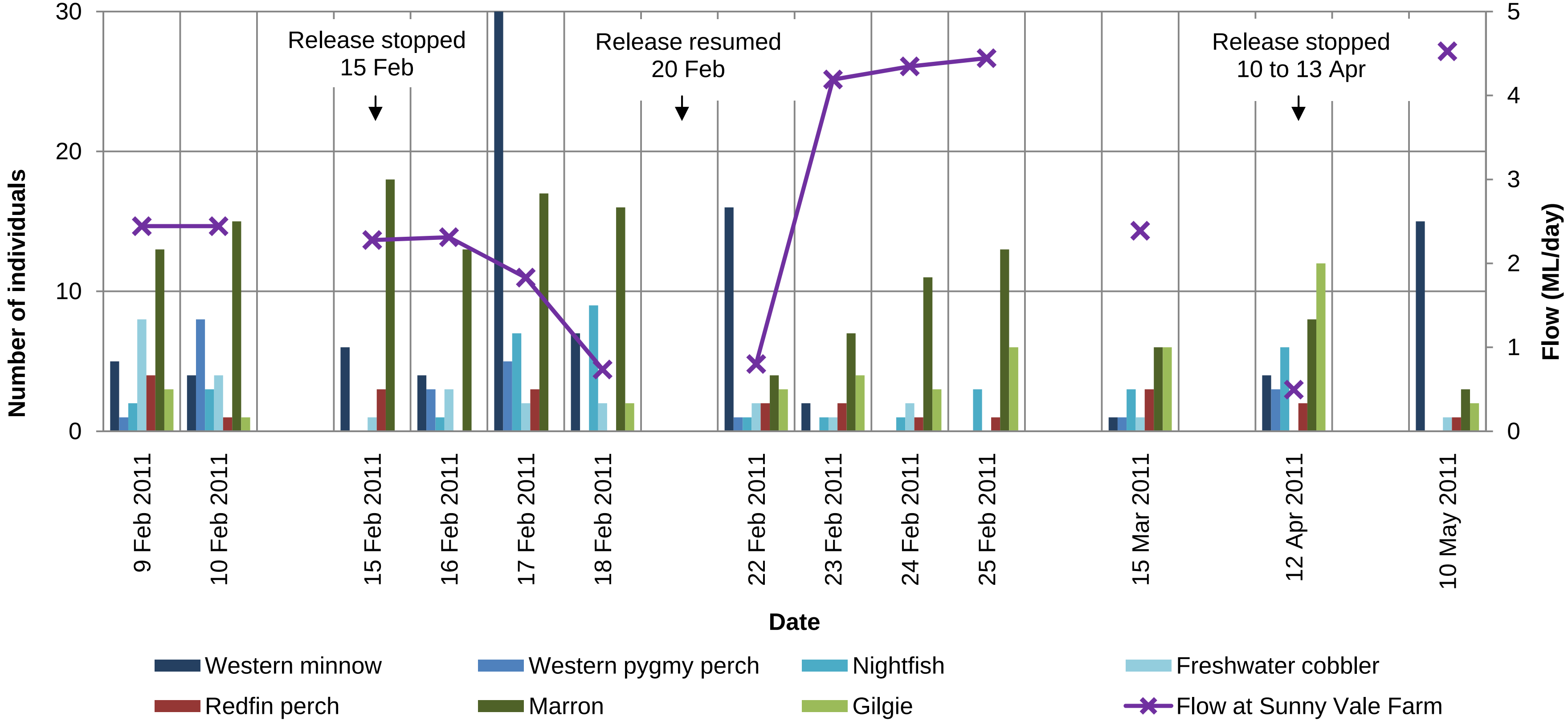


Figure 18   Abundance of fish and crayfish (collected in fyke nets) at the upper site and flow at Sunny Vale Farm gauge

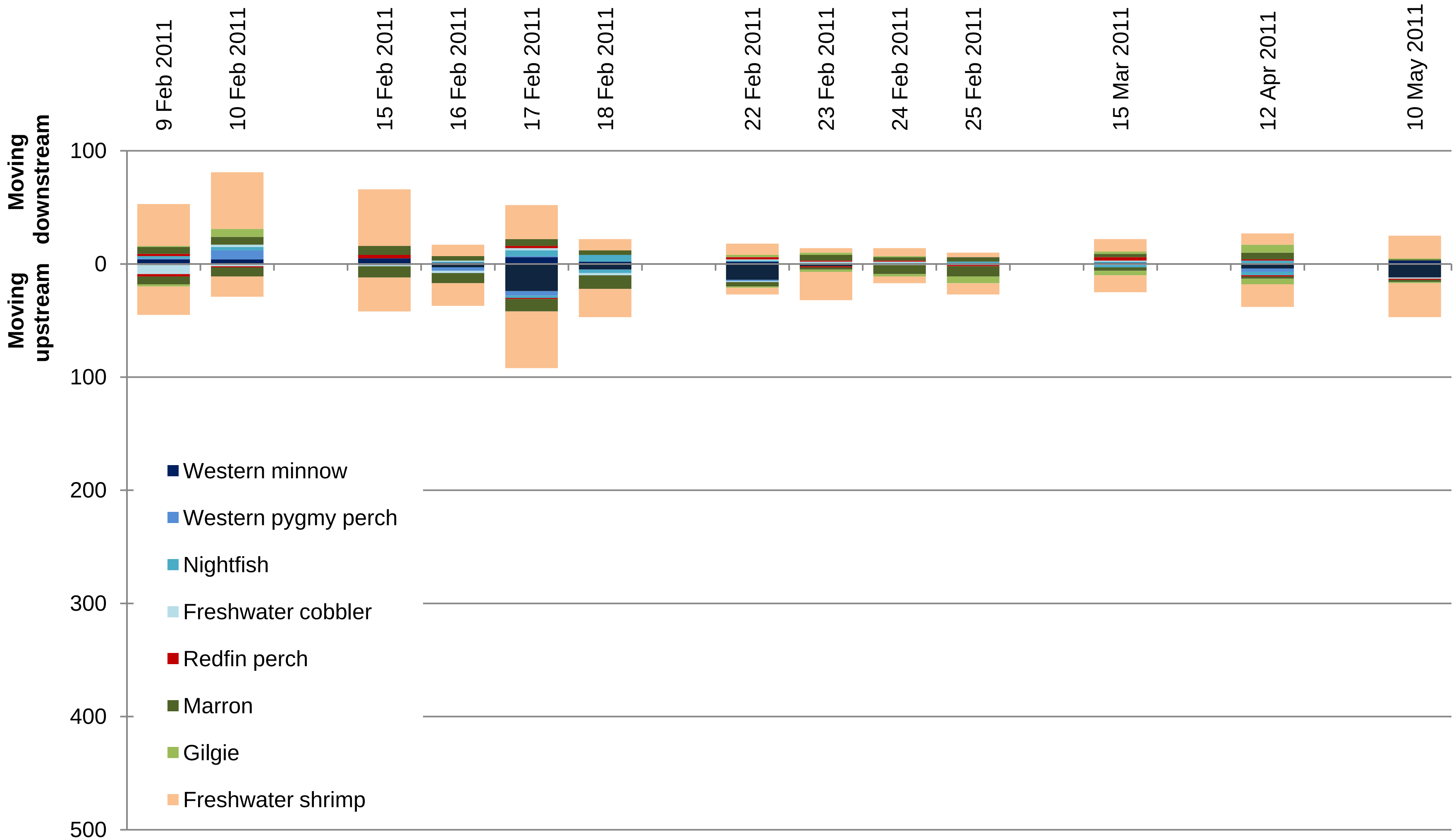


Figure 19 Direction of movement of fish and crustaceans at the upper site

Lower site

At the lower site the mean total abundance of fish and crayfish found in the fyke nets was 71 ± 81 (Figure 20). Freshwater cobbler was the most abundant species before and during the start of the no-release trial. Total abundance of fish and crayfish increased on 17 February, primarily due to a greater number of western minnow than on previous sampling occasions, and increased further on 18 February as a result of a further influx of western minnow, gilgie and marron. In addition, the highest abundance of western pygmy perch and nightfish during the study period was recorded on 18 February. After the water releases resumed, the total abundance of fish and crayfish declined. Total abundance was lower during the March and May samples than the February and April samples.

Variability in the direction of movement of fish and crustaceans was also observed at the lower site, with a considerable increase in the proportion of individuals moving upstream into the pool during the two periods when water releases stopped. The greatest movement of fish and crustaceans occurred on 18 February (three days after water releases ceased) when almost five times as many individuals were moving upstream as on the sampling occasion before the no-release trial. The second-largest movement of biota occurred on 12 April (two days after water releases ceased) when more than 300 individuals (mostly freshwater shrimp) moved upstream into the pool (Figure 21).

Marron, gilgie, western minnow and freshwater cobbler were found in the full range of size classes relevant to each species, while nightfish and western pygmy perch were found in a range of size classes with the exception of the smallest (typically representing the ‘young of year’). Redfin perch were only found in the 0 to 100 mm and 100 to 200 mm size classes (Appendix E).

Signs of reproductive condition (reddening of the urogenital papillae) were noted in female freshwater cobbler on 9, 18 and 22 to 25 February. No signs were noted in males of this species. Reproductive condition (distended abdomen) was observed in western minnow in the April sample.

There were no conspicuous signs of stress or disease observed in the fish and crayfish found. On 22 February the freshwater cobbler were observed to be more vigorous than during the previous sampling occasion on 18 February. On 15 March the marron found in a large trap deployed at 1 m depth were observed to be docile.

Note: a water rat was observed at the lower site during sampling on 21 February.

Table 14 Total abundance of fish and crayfish (collected in fyke nets) at the lower site

Date	9 Feb	10 Feb	15 Feb	16 Feb	17 Feb	18 Feb	22 Feb	23 Feb	24 Feb	25 Feb	15 Mar	12 Apr	10 May
Abundance	74	55	62	46	103	324	92	49	31	35	15	34	3

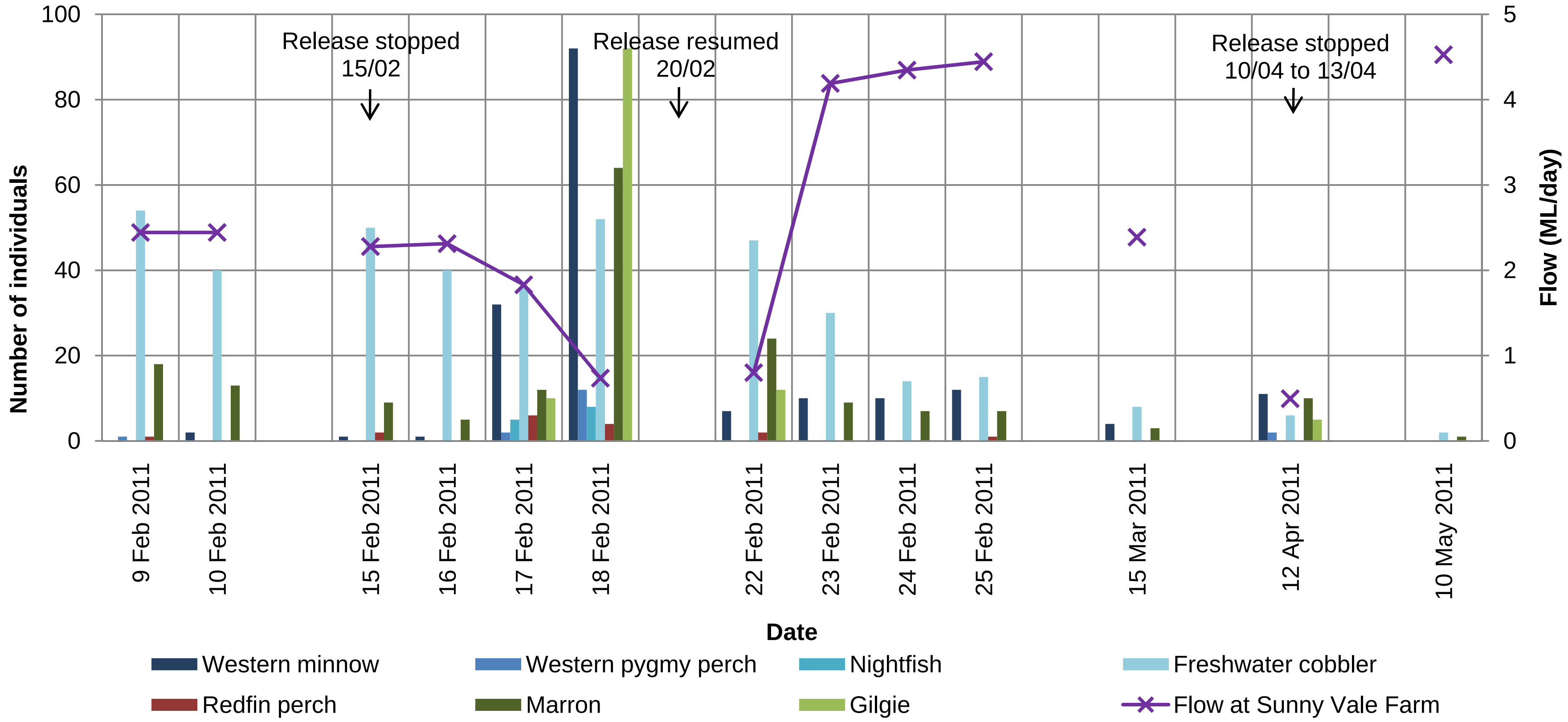


Figure 20 Abundance of fish and crayfish (collected in fyke nets) at the lower site and flow at Sunny Vale Farm gauge

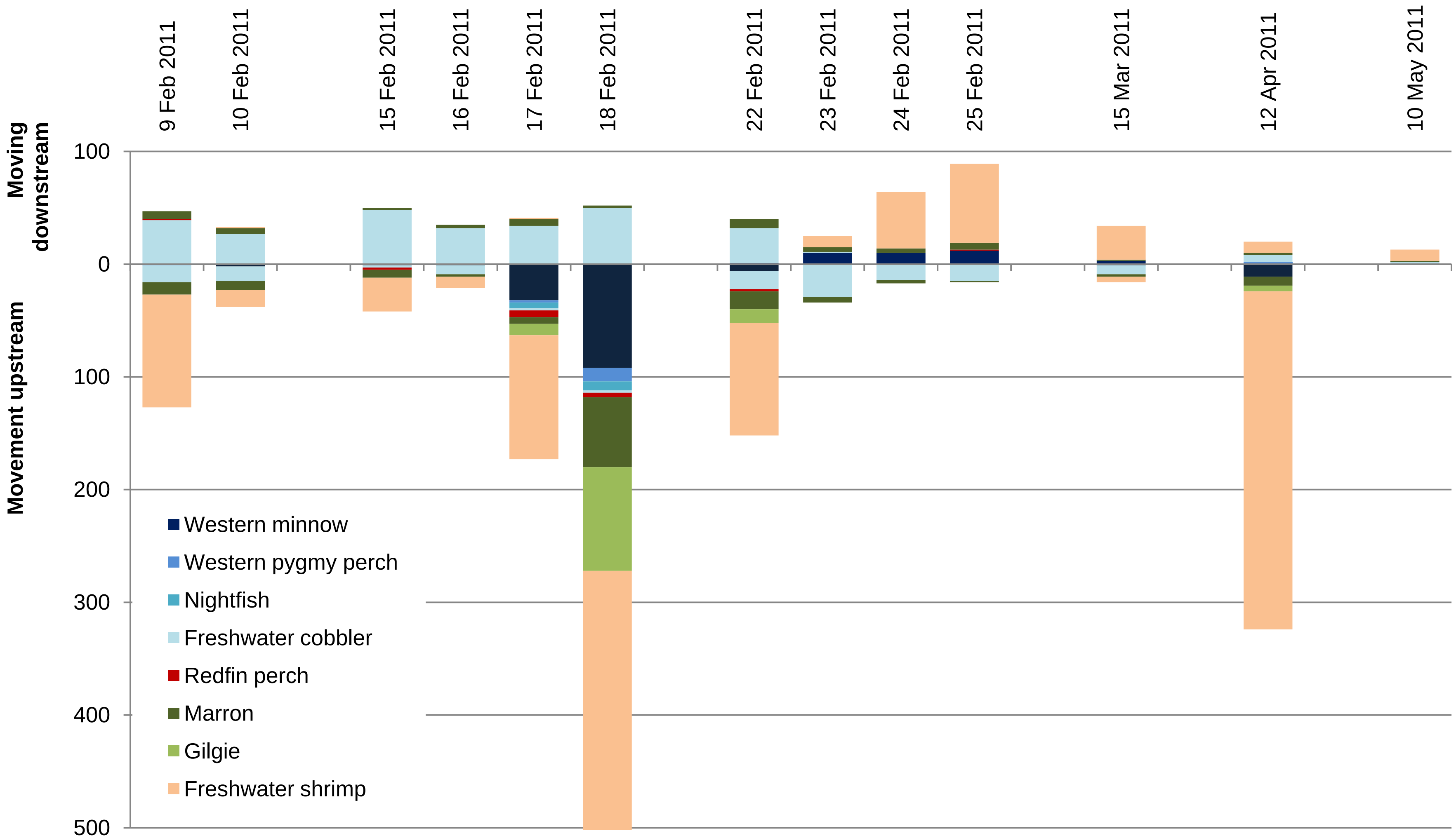


Figure 21 Direction of movement of fish and crustaceans at the lower site

5 Discussion

In late 2010 the EWPs of a number of SWWA river systems were temporarily reduced in response to drying climate conditions and the associated reduction in water availability. For the Harvey River (between Stirling Dam and Harvey Reservoir) several stages of response were agreed, the final one being that between December 2010 and May 2011 a minimum release of 2 ML/day would be applied (refer to Section 2.3).

Given that water availability is likely to decline in the future (based on climate modelling predictions from CSIRO (2009)), a potential management option may be to control releases based on the volume of water flowing into the dam. This is likely to result in releases from Stirling Dam stopping, given that the Harvey River upstream of the dam has experienced no-flow periods during the past 10 years (WRM 2010).

This study assessed whether the flow provided by the release of approximately 2 ML/day from Stirling Dam for December 2010 to May 2011 was sufficient to maintain the health of the aquatic ecosystem, and assessed the impact of stopping the release of water from the dam.

Given that this study began after the minimal release period started (i.e. baseline data was not collected as part of the study), it was not possible to quantify any direct impacts of the change in flow volume. In lieu of this, the status of the river system was assessed by comparison to a reference condition compiled from a number of sources that represent a reasonable expectation for the ecological health of a river system of this form and function.

5.1 Ecological health under minimal water release conditions

The assessment of general ecological health is based on data collected throughout the study period, but with a focus on periods when water was being released from the dam. This encompasses the following periods:

- before the no-release trial (7–14 February, mean flow 2.3 ML/day as recorded at the Sunny Vale Farm gauge) and
- between the end of the no-release trial recovery period (nominated as being when dissolved oxygen returned to 5 mg/L) and the inspection works (6 March to 8 May, mean flow 2.5 ML/day).

Upper site

The habitat at the upper site appeared to be in good condition (relative to the reference condition, refer Section 4.2). The vegetation in the riparian zone was structurally intact (i.e. upper, mid and lower storey were present), a high proportion of the banks were shaded by vegetation and a range of different in-stream habitats were available (e.g. pool, riffle, variation in flow velocity and water depth, inundation of woody debris, inundation of macrophytes and epiphytes and draping vegetation). There were a combination of steep and gently sloped banks, with the left bank being steep and approximately 3 m high, and the right bank having both steep and gentle sloping areas of approximately 1.5 m in height.

The dissolved oxygen, specific conductivity and pH values measured during the periods listed above were within the guidelines established in the reference condition (Section 4.3), as was the mean turbidity within the data collection period (14 March to 13 April 2011). The mean water temperature measured was within the ‘normal range’ identified in the reference condition (Section 4.3). Some maximum and minimum values recorded were outside the ‘normal range’ but appear to correlate with periods of high and low air temperature respectively (Appendix D). The diel temperature range exceeded the 4°C range established in the reference condition (Appendix D) on several days during the periods listed above, primarily as a result of high daytime air temperatures. Given that the ‘normal range’ and diel temperature range used in the reference condition are indicative values, and given the shading provided by the intact riparian vegetation, the occurrence of temperatures a few degrees centigrade outside of these ranges is not a cause for concern.

The species richness of fish and crayfish at the upper site was equal to that identified in the reference condition (Section 4.4). The total abundance of fish and crayfish varied slightly throughout the study period (Figure 18); however, except for the increase in abundance during the no-release trial, the differences are likely to be due to natural variability between samples. The size class and abundance data suggests the presence of robust populations of marron, gilgie and western minnow. In addition, signs of reproduction in western minnow were noted in the May sample.

Western pygmy perch and nightfish were not found in the size class representing ‘young of year’: this could be a result of the timing of sampling compared with spawning. Both species have relatively long spawning periods – typically between July and November for western pygmy perch and between August and September for nightfish (Morgan et al. 2011) – hence if spawning in the Harvey River largely occurred towards the start of these periods, it is possible that the ‘young of year’ exceeded the smallest size category. Alternatively, the data could demonstrate that the upper site is not a natural nursery area for these species, or that they are avoiding the open water of the pool environment because it offers less protection from the predators present (freshwater cobbler, marron and redfin perch) compared with the run environments occurring downstream. Given that both species reach sexual maturity after one year – or two years for female nightfish (Morgan et al. 2011) – and that larger individuals of both species were present, it is likely that successful recruitment has occurred during the past few years. In addition, signs of reproduction were observed in the nightfish in March and April. While this suggests that the Harvey River is able to sustain the populations of these species, further work would be required to clarify this point and to identify nursery areas for protection.

Freshwater cobbler were found in a range of size classes but in relatively low abundance compared with the lower site: this suggests that the upper pool site is not a primary refuge for this species.

Redfin perch were found in low abundance in a range of size classes, with the majority of individuals being 'young of year'. This non-native species was introduced into SWWA in the 1890s for recreational angling (Morgan et al. 2011). The presence of redfin perch in the Harvey River is not a direct function of modifications to flow, however it does warrant consideration in the management of EWPs given the potential for increased predator fitness if species congregate in refuge pools under low-flow conditions. For example, ensuring that pools do not become disconnected, or increasing the availability of habitat that provides shelter for native species, would help the native species avoid predation.

Based on general observations of fish and crayfish condition, no conspicuous signs of stress or disease were apparent during the study period.

In summary, aquatic ecosystem health at the upper site was in relatively good condition based on water quality being within reference condition ranges, the presence of intact riparian vegetation and in-stream habitats, and the presence of viable native fish and crayfish populations expected under the reference condition. As such, the agreed minimum release of 2 ML/day of water from the dam, which provided a mean flow of 2.4 ML/day at Sunny Vale Farm gauge, appears to be sufficient to maintain ecosystem health.

Lower site

At the lower site the structure and availability of the habitat is considered to be degraded (relative to the reference condition, refer Section 4.2) based on the mid and under storey layers of riparian vegetation being largely absent and the presence of exotic grasses and blackberry shrubs. WEC et al. (1997) attributed the reduced cover of mid and under storey vegetation to past uncontrolled livestock access. Decreased cover of riparian vegetation has various implications for aquatic ecosystems including:

- reduced shading, leading to increased temperature (Davies et al. 2004) and increased light availability for aquatic plant and algal growth (Quinn et al. 1997)
- decreased allochthonous inputs and consequent impacts on the food web (Pusey & Arthington 2003)
- decreased bank stability (McKergow et al. 2003)
- decreased habitat provision; for example, woody debris (Pusey & Arthington 2003)
- decreased filtering of nutrients (Naiman & Decamps 1997).

As such, the resilience of the ecosystem to low-flow conditions is likely to be affected; for example, the water temperature in an isolated pool with limited shade is likely to increase more rapidly than in one with shade.

The tall, steep-sided banks may have been caused by past releases for white-water canoeing (WEC et al. 1997). Areas of slumping and bedrock provide patches of gently sloping edge habitat that is important for biota (e.g. for shelter and foraging for crayfish (Benvenuto et al. 2008, Jowett et al. 2008)). A range of in-stream habitats were present (e.g. pool, riffle, inundation of woody debris, inundation of macrophytes and draping vegetation, variation in flow and depth).

The mean water quality values were within reference condition ranges for the majority of the periods listed above with the notable exception of dissolved oxygen levels before the no-release trial began (7–14 February 2011). While continuous readings taken 0.1 m below the water surface were above the level thought to cause stress to biota (5 mg/L, refer Section 4.3), spot readings taken at greater depths (0.4 to 0.2 m) in the ‘fyke pool’ were below this reference level. The minimum value, recorded at the bottom of the pool, was 2.7 mg/L. Given that fish and crayfish are able to move to areas of higher dissolved oxygen, this pocket of low dissolved oxygen is unlikely to affect the biota, however it should be noted that such pockets have developed after a relatively short period of minimal flows (mean flow of 2.7 ML/day for 26 days)[2]; as such, monitoring may be useful during periods of extended minimal releases in future.

Spikes in turbidity outside the guideline range occurred, but given the infrequent and temporary nature of these increases (maximum of 10 minutes) they are likely to indicate fouling of the probe rather than pulses of high turbidity.

The species richness of fish and crayfish at the lower site was equal to that of the reference condition (Section 4.4). Freshwater cobbler was the most abundant species present (excluding the periods when the water releases ceased) (Figure 20), with a mean of 45 individuals before and during the no-release trial. This suggests that the pool is a key habitat for the population of freshwater cobbler in this part of the reach, and that it provides an important refuge for the species during periods of minimal water releases (approximately 2 ML/day). Signs of reproductive condition (reddening of the urogenital papillae) were noted in some female freshwater cobbler before, and at the end of, the no-release trial, as well as in the April sample. This suggests that freshwater cobbler are reproducing in the river system, however the lack of evidence of spawning or later stages of reproductive condition (distended abdomen) suggests that spawning may have occurred before the study began or may have been interrupted by sampling activity.

The total abundance of fish and crayfish found in the fyke nets was considerably lower in the May sample than on any other sampling occasion. Given that this was the last sampling event it was not possible to quantify further changes in abundance, however it is likely that the low abundance in May was due to natural seasonal variability, with biota dispersing out of the pools in response to higher flow in late April and early May.

The size class and abundance data suggests a robust population of marron, gilgie and western minnow. ‘Young of year’ of the western pygmy perch and nightfish were not found, however as was noted with the upper site, the presence of individuals in

[2] The mean daily flow recorded at Sunny Vale Farm gauge was 2.7 ML/day during the 26 days before the start of the no-release trial; previous to this flow was greater than 3 ML/day for approximately two years.

other size classes suggests that the population has been refreshed in recent years. Also, a small increase in abundance of both species was seen during the no-release trial, which suggests that individuals are present in the system but prefer other habitats and only move into the pool under drying conditions.

As with the upper site, the presence of redfin perch at the lower site warrants management consideration given the potential for increased predation in refuge pools under low-flow conditions.

No conspicuous signs of stress or disease were observed in the fish and crayfish throughout the study period. The observation that marron (caught in a large trap deployed at 1 m depth on 15 March) were docile suggests that they may have been suffering the effects of localised low dissolved oxygen, however this cannot be confirmed because spot samples of dissolved oxygen were not taken on 15 March. Based on continuous data collected 0.1 m below the water surface, the minimum dissolved oxygen reading on 15 March was 5.1 mg/L.

Aquatic ecosystem health at the lower site appeared to be in relatively good condition, based on water quality being within reference condition ranges, the presence of in-stream habitats and a viable native fish and crayfish population. This suggests that the agreed minimum release of approximately 2 ML/day of water from the reservoir, which provided a mean flow of 2.4 ML/day at Sunny Vale Farm gauge, appears to be sufficient to maintain ecosystem health at the lower site.

The results indicate two areas for concern regarding the resilience of the ecosystem: habitat and dissolved oxygen. The lack of intact riparian vegetation has reduced the structure and availability of the habitat at the lower site (reducing shading, reduced draping vegetation) which has implications for biota fitness (e.g. impacts on foraging, shelter and spawning (WRC 2000, Pusey & Arthington 2003)) and may reduce the resilience of the ecosystem to accommodate other pressures (e.g. low-flow conditions). Low dissolved oxygen (below 5 mg/L) was observed before the no-release trial. This suggests that the release of approximately 2 ML/day of water from the dam (which provided a mean flow of 2.7 ML/day at Sunny Vale Farm gauge over the 26 days before the no-release trial) can result in pockets of low dissolved oxygen over a period of time. While biota are able to move away from these pockets to areas of higher dissolved oxygen, it indicates the potential for more-widespread low dissolved oxygen in response to low flow.

5.2 Ecological health under no-release conditions

The assessment of ecological health under no-release conditions is based on data collected throughout the study, but with a focus on two periods when releases of water were stopped, and the associated recovery period (nominated as being when dissolved oxygen returned to 5 mg/L) after releases resumed. This encompasses the following periods:

- no-release trial (15–21 February, mean flow 1.2 ML/day as recorded at Sunny Vale Farm gauge)

- recovery after the no-release trial (22 February to 5 March, mean flow 3.1 ML/day)
- inspection works (9–12 April, mean flow 1.2 ML/day)
- recovery after inspection works (13–19 April, mean flow 6.4 ML/day).

Upper site

A number of changes in habitat availability were observed during the periods when water was not released from the reservoir. The most notable change was the near complete loss of the riffle habitat, which is likely to have affected the abundance and community composition of macroinvertebrates in this habitat (Boulton 2003). Reduced inundation of in-stream habitats such as banks, bed substrate, detritus and draping vegetation was observed, although these habitats were still present in other parts of the site. The water depth at the depth reference points in the pool reduced by 0.15 m during the no-release periods, however given that the pool was approximately 0.95 m deep (at the deepest point) under 2.3 ML/day of flow (recorded at Sunny Vale Farm gauge), the reduction in depth did not compromise the persistence of the pool habitat.

A response to the cessation of water releases was observed in several of the water quality parameters. Dissolved oxygen declined and specific conductivity increased, although both remained within the guideline ranges established in the reference condition (Section 4.3). Both parameters returned to previous levels during the recovery periods however there is insufficient evidence to determine the extent or rate of decline if the releases had not been resumed.

Continuous data shows that pH decreased during both no-release periods but remained within the reference condition ranges (Appendix D). By contrast, spot measurements, taken at a different location in the pool (at the edge), were just outside the guideline range (maximum of pH 8.5 compared with the guideline upper limit of pH 8.0, ANZECC/ARMCANZ 2000a) between 23 and 25 February (i.e. after water releases resumed). Given that the guideline range specified by ANZECC/ ARMCANZ (2000a) is indicative, a value of pH 0.5 above the upper limit is not a cause for concern.

During the inspection works the mean turbidity was below the guideline values (5 NTU compared with 10–20 NTU, refer Section 4.3) but the turbidity spiked at the end of the inspection works, reaching a maximum 197.5 NTU on 12 April. Given that the high turbidity was temporary (approximately 1.5 hours) it is unlikely to have had lasting ecological consequences.

The total abundance of fish and crayfish increased considerably on 17 February compared with that found during the previous samples, and corresponds with decreased flow at the site as a result of the water releases being stopped on 15 February (Figure 18). The increase was primarily caused by a large abundance of western minnow (30 individuals), along with a small increase in the abundance of nightfish. This suggests that these species may have been moving into the pool in response to the decrease in flow.

General observations of the condition of individual fish and crayfish suggest that there were no conspicuous signs of stress (behavioural or physical) or disease during the periods when releases were stopped.

Based on the indicators assessed, ecosystem health at the upper site was broadly maintained during the no-release periods. The pool habitat persisted throughout both periods, as did other in-stream habitats (albeit at reduced availability). The mean water quality values were within reference condition guidelines. The increase in abundance of fish and crayfish suggests that the pool provided a refuge function, and the habitat and water quality were sufficient to sustain the biota during these periods. The key impact of water releases stopping was the near complete loss of riffle habitat, which is likely to have affected riffle-dwelling macroinvertebrates.

Lower site

As with the upper site, a number of changes in habitat availability were noted at the lower site during the no-release periods. These included reduced water depth and width and reduced inundation of in-stream habitats such as banks, bed substrate, large woody debris, detritus and draping vegetation. The most notable change was the near complete loss of the riffle habitat, which is likely to have affected the abundance and community composition of macroinvertebrates in this habitat (Boulton 2003). Water depth at the two depth reference points in the pools reduced by between 0.21 and 0.29 m during the no-release periods; however, given that the ‘manta pool’ was approximately 0.8 m deep (at the transect) and the ‘fyke pool’ was approximately 2.1 m deep (at the deepest point) under 2.3 ML/day of flow (recorded at Sunny Vale Farm gauge), the reduction in depth did not compromise the persistence of the pool habitat.

Several of the water quality parameters measured showed a response to the reduction in flow resulting from water releases stopping. Dissolved oxygen levels, measured continuously at 0.1 m below the water surface, decreased rapidly during the no-release trial (by 3 mg/L over four days). Dissolved oxygen fell below the level able to support fish (<2 mg/L, Waterwatch 2002), remaining below this threshold for approximately 44 hours. During this period, spot readings, taken at numerous locations (between 12 and 15) within the site and at different water depths, were also low (between 0.9 and 3.4 mg/L). It was not possible to locate ‘pockets’ of higher dissolved oxygen using spot measurements, although it is feasible that such pockets existed in parts of the pool that were not accessible for sampling (e.g. beneath the draping blackberry shrub).

Dissolved oxygen also decreased when releases were stopped to allow inspection works: it declined by 5 mg/L over four days, although the minimum value recorded (3.2 mg/L) was above the level able to support fish (<2 mg/L, Waterwatch 2002). The decline in dissolved oxygen observed at the lower site was unusually rapid compared with refuge pools in other river systems (Tim Storer, pers. comm.). Given that biochemical oxygen demand was found to be <5 mg/L on 15 February, and that there were no obvious signs of chemical pollution, it is unclear why the dissolved oxygen declined so rapidly.

The total abundance of fish and crayfish increased considerably on 17 and 18 February compared with that found during the previous samples, and corresponds with decreased flow at the site (Figure 20). The increase was primarily caused by a high abundance of western minnow on 17 February and of western minnow, marron and gilgie on 18 February. In addition, the highest abundance of western pygmy perch and nightfish during the study period was recorded on 18 February. This suggests that these species may have been moving into the pool to seek refuge in response to the decrease in flow. The dominance of upstream movement during this period (Figure 21) also suggests that fish and crustaceans were seeking refuge, given that the run immediately downstream from the lower site was dry on 21 February (six days after water releases ceased), resulting in the pool being disconnected from the downstream river system.

The abundance of freshwater cobbler fluctuated between 9 and 22 February but did not increase noticeably during the no-release trial. Although they did not appear to respond to the reduction in flow, it is possible they were already using the pool as a refuge during the period of minimal water releases (which provided a mean flow of 2.7 ML/day for 26 days[3]). The abundance of freshwater cobbler declined during the recovery period after the no-release trial, which could suggest that the release of a pulse of water at the end of the trial (resulting in a flow of approximately 4 ML/day at Sunny Vale Farm between 23 and 25 February) provided sufficient depth of water to allow passage of these large-bodied fish out of the refuge pool (via a run at the downstream end or riffle at the upstream end of the pool), or that it triggered the dispersal of the freshwater cobbler from the pool.

The total abundance of fish and crayfish increased during the second no-release period (9 to 12 April). While the total abundance was considerably lower than during the no-release trial, it was double the total abundance found in the March sample. This suggests that while fish and crayfish may have dispersed from the site during March, the individuals remaining in that part of the reach responded to the reduction in flow between 9 and 12 April by moving into the pool to seek refuge. The high abundance of freshwater shrimp found moving upstream on 12 April (Figure 21) also suggests a response to the reduction in flow.

As with the upper site, there were no conspicuous signs of stress or disease during the periods when releases were stopped. The observation that freshwater cobbler were more vigorous on 22 February than on 18 February suggests that the fish may have been affected by the low dissolved oxygen levels in the pool, however there were no clear indications of behavioural change or stress (e.g. gulping for air at the water surface).

In summary, ecosystem health at the lower site appeared to decline during periods when no water was released from the dam, based on the rapid decline of dissolved oxygen, the near complete loss of riffle habitat and the reduction of in-stream habitat availability. Despite the decline in dissolved oxygen, the increase in abundance of

[3] The mean daily flow recorded at Sunny Vale Farm gauge was 2.7 ML/day during the 26 days before the start of the no-release trial; previous to this flow was greater than 3 ML/day for approximately two years.

fish and crayfish suggests that the pool provided a refuge function during these periods.

There were some indications that if water releases had not resumed after four or five days, water quality may have declined further, which may have compromised the refuge function of the pool. The decline in dissolved oxygen is likely to have continued and may have resulted in the pool becoming anoxic. The increase in specific conductivity and decrease in pH observed during these periods (Appendix D) may have continued further had water releases not been resumed. As such, water quality monitoring may be beneficial if water releases are stopped for extended periods of time.

5.3 Additional management considerations

Social and economic requirements

A number of social and economic values were identified within the reach, including the water abstraction points at the downstream end of the reach. Future revisions of the EWP would need to take these social and economic requirements into account.

Fish passage

An assessment of the impact of reduced flows on fish passage through the Harvey River (between Stirling Dam and Harvey Reservoir) was beyond the scope of this study, however it is important to consider fish passage in future management scenarios. An assessment of all the natural and artificial barriers to fish passage is recommended to determine the minimum flow required to maintain connectivity for biota.

Riparian vegetation

While this study considered the structural intactness of the riparian vegetation, an assessment of the impact of reduced flow on riparian vegetation condition (i.e. plant health and species composition) was beyond the scope of this study, however it is important to consider the supply of water for riparian vegetation growth in future management scenarios. An assessment of the riparian vegetation condition is recommended to determine the minimum flow required to maintain riparian vegetation in good condition.

Water rat

A water rat was observed at the lower site during the study. Given that the water rat is listed as a Priority 4 species (in need of monitoring) under the provisions of the *Wildlife Conservation Act 1950* (DEC 2010), further study is recommended to confirm the presence of a water rat population and to determine how that population might be affected by changes in water provision.

6 Conclusions

The results of this study suggest that the minimum release of approximately 2 ML/day from Stirling Dam (which provided a mean flow of 2.4 ML/day at Sunny Vale Farm gauge) was sufficient to maintain the health of the aquatic ecosystem in the Harvey River (between Stirling Dam and the Harvey Reservoir) during the study period, based on the following:

- water quality was within reference condition guidelines
- there was sufficient water to inundate the micro and macro habitats present
- there was a viable population of the native fish and crayfish species identified in the reference condition.

One minor concern was the observation of pockets of low dissolved oxygen (below 5 mg/L) in the pool at the lower site following a period of 26 days of minimum releases (which provided a mean flow of 2.7 ML/day at Sunny Vale Farm gauge). It is possible that if flow had continued at this volume for an extended period of time, more widespread areas of low dissolved oxygen could have developed.

Further, the results of the study suggest that stopping the release of water from Stirling Dam had a detrimental impact on the health of the aquatic ecosystem at the lower end of the reach, based on the following: dissolved oxygen declined rapidly and to levels below those identified as critical in the reference condition (refer Section 4.3); riffle habitats were not maintained; and the loss of inundation of in-stream habitats was likely to be detrimental to biota, given that the habitat was already affected by steeply incised banks and the lack of mid and under storey vegetation.

During the no-release trial the sensitivity of the river system to changes in flow became apparent. At the lower site flow decreased two days after releases ceased, and continued to decline for a further four days. Water quality changes occurred in response to the decrease in flow, with dissolved oxygen declining by 3 mg/L over four days. Biota also responded rapidly to the reduction in flow, with increases in abundance occurring after two days of no release. This suggests that the aquatic ecosystem can tolerate brief no-release periods in summer – if required for management purposes (e.g. maintenance work) – however the length of time available before ecosystem health declines will depend on conditions in the pool at the start of the period (e.g. dissolved oxygen levels).

In addition, if a no-release period is required during summer, consideration should be given to the volume of water released at the end of the period. The release of a large volume of water (as occurred on 14 April after the inspection works) creates an unseasonal pulse of high flow. Given that the lifecycle activities of many fish are related to flow (e.g. pre-spawning condition, spawning, and the survival of larvae and juveniles), the provision of unseasonal flow cues may affect the fish population (Norton et al. 2010).

The increase in total abundance of fish and crayfish during the no-release trial suggests that the pools provide an important refuge under low-flow conditions. The difference in relative abundance of species at the two sites suggests that the pools provide refuge for different species, hence the protection of one pool does not necessarily mean than all species present in the river system will be protected. For example, given the high abundance of freshwater cobbler at the lower site, both before and during the no-release trial, it is likely that this pool is a key habitat for this species and provides it refuge both under minimal release and no-release conditions.

Several operations issues were noted during the course of the study. There was a discrepancy between the way that the EWP and the dry-season requirements were described, and in the arrangement for compliance monitoring. The monthly EWP volumes specified in the WRMOS (DoW 2009a) are ‘release volumes to achieve monthly flow volumes’, with compliance monitoring to be undertaken at Sunny Vale Farm gauge (6 km downstream from the dam wall). The temporary revision of the EWP was described as a ‘minimum release’ and compliance arrangements were not specified. Given that there is a difference between the volume of flow recorded at Stirling Below gauge (0.8 km downstream from the dam) and that recorded at Sunny Vale Farm gauge (6 km downstream from the dam), this may suggest that the reach is receiving a groundwater contribution, or that there is a difference in calibration between the gauges. As such, the flow data from Sunny Vale Farm gauge does not necessarily represent the volume of water released from the dam.

7 Recommendations

Based on the results of this study it is recommended that the monthly EWP flow volumes for the Harvey River (between Stirling Dam and Harvey Reservoir) be revised for the months of January to April. Given that low dissolved oxygen levels (below 5 mg/L) were recorded following a period of mean flow of 2.7 ML/day, it is recommended that the monthly EWP flow volumes for January to April be revised to provide a minimum daily flow of 2.7 ML/day (as recorded at Sunny Vale Farm gauge).

If the daily flow falls below the threshold of 2.7 ML/day (at Sunny Vale Farm gauge), it is recommended that monitoring be initiated to check whether dissolved oxygen levels are above 5 mg/L (the level thought to cause stress in biota (Koehn & O'Connor 1990)). If dissolved oxygen is found to be below 5 mg/L, the Department of Water and Water Corporation should agree on an appropriate course of action based on the conditions found (e.g. undertake further monitoring or increase releases to provide more flow). An outline of the response protocol, following a breach of the flow threshold, is provided in Appendix F.

It is also recommended that the WRMOS be revised to state that stopping water releases should be avoided where possible, particularly during summer, and that if releases need to be stopped:

- the Water Corporation must notify the Department of Water in advance
- before the stoppage, a spot check of water quality should be undertaken, and the results discussed with the Department of Water's Environmental Water Planning Section
- during the course of the stoppage the response protocol, outlined in Appendix F, should be initiated
- at the end of the stoppage, the Department of Water and Water Corporation should agree on the volume of water to be released, based on the ecological needs of the aquatic ecosystem at the time.

If, in future, it is proposed that the monthly EWP flow volumes are revised to provide a daily flow of less than 2.7 ML/day, further study is recommended to test the ecosystem response to the proposed flow volume, including assessing the level of dissolved oxygen in the pools adjacent to Sunny Vale Farm gauge (based on the rapid decline in dissolved oxygen observed during this study).

Further, it is recommended that:

- any future temporary revisions to the EWP are specified as either 'release volumes' or 'flow volumes' and that the gauging station for compliance monitoring is clearly identified
- the difference in volume between flow recorded at Sunny Vale Farm gauge and Stirling Below gauge be investigated to determine whether the difference

is due to a contribution from groundwater or due to an error in calibration of the gauges.

A number of knowledge gaps were identified during the course of the study. It would be beneficial for management of the river system if the following gaps were addressed:

- investigate the cause of the rapid decline in dissolved oxygen under no-release conditions at the lower site, and the way in which native fish were able to tolerate the low dissolved oxygen conditions (e.g. accessing pockets of higher dissolved oxygen)
- clarify the viability of populations of western pygmy perch and nightfish, and the location of nursery sites for these species to ensure the EWPs provide adequate flow to maintain the nursery function
- determine the minimum flow required to maintain fish passage along the length of the river during seasons relevant to fish spawning, particularly the requirement for freshwater cobbler to move upstream in spring/summer to spawn
- determine the optimum flow requirements of the ecosystem following any no-release periods (e.g. after stoppages for inspection works) to ensure that the flow volume is sufficient to assist the ecosystem health to recover, but does not create a pulse of high flow that may trigger an unseasonal response in biota
- assess the condition of riparian vegetation in relation to changes in flow regime
- confirm the presence of a water rat population.

Appendices

Appendix A — Coordinates of study sites

Table A1 Coordinates of sites assessed as part of this study

Site name (and code)	Location description	Latitude	Longitude
Upper (HARV07)	Upstream from crossing/camp	-33.1271	116.01225
Lower (HARV08)	Sunny Vale Farm gauging station	-33.10758	115.98966
Flow 1	Crossing/camp	-33.127439	116.011204
Flow 2 (HARV05)	136 Hanson Rd	-33.114267	115.998067

* Coordinate system World Geodetic System 1984 (WGS84)

Appendix B — Field sheets

Date ______________ Site code ______________

Government of Western Australia
Department of Water

SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
COVER SHEET

SITE CODE ________________

SWMA ______________________________

RIVER SYSTEM ______________________________

RIVER/STREAM NAME ______________________________

SITE NAME ______________________________

DATE ______________ COC __________ SAMPLE NUMBER ______________

NAME OF SAMPLERS ______________________________

NOT ASSESSED IN FIELD

ALTITUDE ______ (m) SLOPE ________ (m/km) DFS ________ (km) STREAM ORDER ______ (km)

NEAREST RAINFALL STATION ________ (name) DISTANCE AWAY _____ km AVERAGE ANNUAL RAINFALL _____ (mm)

FLOW PATTERN CATEGORY ______________ DISCHARGE CATEGORY ________ (mm)

ORDER OF SAMPLING – DAY 1

1. Take water quality samples: grab followed by in-situ
2. Collect macroinvertebrates
3. Deploy water quality loggers. *Note: after loggers have been deployed only enter river downstream.*
4. Process macroinvertebrate sample
5. Deploy fish/crayfish traps and fyke nets
6. Site photos (important to capture conditions on first day as factors such as water level and flow can change rapidly)
7. Field sheets (if time permits)

ORDER OF SAMPLING – DAY 2

1. Collect fish/crayfish traps and fyke nets
2. Collect water quality loggers: after 25 hours (144 logged measurements)
3. Complete field sheets
4. Complete site photos: fill-in checklist below.

Photo checklist

[ ] Upstream and downstream photos; taken at the top, middle and bottom of the 100m sampling site (6 photos total)
[ ] Representative site photos
[ ] Macroinvertebrate sampling area
[ ] Representative video taken
[ ] Canopy shots (taken from edge of stream of both sides – representative of density of canopy throughout site)

Acronyms
LB: Left Bank, **RB:** Right Bank

Version 12 - November 2009 Page 1 of 19

Date ______________ Site code ______________

Government of Western Australia
Department of Water

SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS

GPS DATUM ______________

LONGITUDE (°E) or EASTING ______________

LATITUDE (°S) or NORTHING ______________

MAP NAME and YEAR OF PUBLICATION ______________ SCALE ______________

PAGE REFERENCE OR MAP NUMBER ______________

ACCESS DETAILS ______________

____

____

____

PROPERTY OWNER ______________

PHONE NUMBER ______________

ADDRESS ______________

NOTIFY BEFORE EACH VISIT [ ] Yes [ ] No PERMISSION REQUIRED [ ] Yes [ ] No

KEY REQUIRED [ ] Yes [ ] No KEY NUMBER / AVAILABLE FROM ______________

ACCESS MAP – SKETCH ROUTE BELOW OR ATTACH MAP TO BACK OF FIELD SHEET

Include flow direction, site location, roads, crossings, north arrow, distances and landmarks.

MAP ATTACHED ☐

Version 12 - November 2009

Page 2 of 19

Date ______________ Site code ______________

Government of Western Australia
Department of Water

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

Artists name ______________________

LONGITUDINAL DIAGRAM (AERIAL VIEW)

Essential features	Legend
Flow direction	→ → →
Loggers	(L)
Macroinvertebrate sample	(M)
Water quality sample	(W)
Fyke nets	▶ or ◀
North arrow	↑ N

Possible features	DIY legend	*Possible features*	DIY legend
Macrophyte habitat		Vegetation type A: ______	
Large trees		Vegetation type B: ______	
Woody debris		Vegetation type C: ______	
Riffles			
Sandbars/sediment deposits			
Significant erosion			
Natural or artificial barriers			

Version 12 - November 2009

Page 3 of 19

Date ______________ Site code ______________

Government of Western Australia
Department of Water

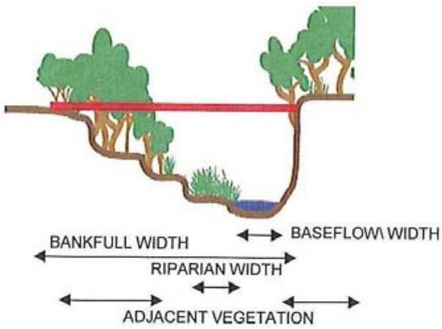
SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
GENERAL SITE ASSESSMENT – 100m sampling site

CROSS SECTION DIAGRAM

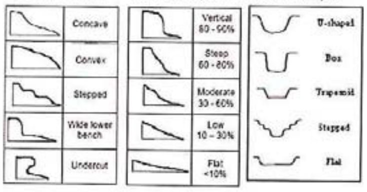
Representative of sampling region (where high variability exists draw two cross-sections).

Suggested information to include on cross section diagram above

- Bank shape (see below)
- Bank slope (see below)
- Channel shape (see below)
- Base-flow and bank-full width (m)
- Streamside and adjacent vegetation width and structure
- Presence of bars, benches, toes



Circle diagrams below



STREAM WIDTH MEASURMENTS

	Top	Middle	Bottom
Bankfull width (m)	______	______	______
Current water width (m)	______	______	______

Water width compared to base-flow (circle)				
No flow dry isolated	Low < low water mark	Moderate Equal to base-flow	High > high water mark	Flood

Version 12 - November 2009

Page 4 of 19

Date ______________ Site code ______________

Government of Western Australia
Department of Water

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)	

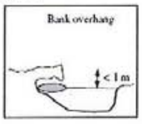
*Note: section relates to habitat (not shading). ** Dead vegetation not included*

Roots overhanging and draped in water			
None	Limited	Moderate	Extensive
Overhanging banks			
None	Limited	Moderate	Extensive

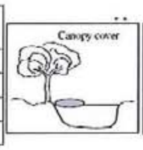
Limited = 1-10% of bank length, Moderate = 11-50%, Extensive >50% of bank.

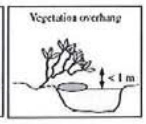
Flow (circle)
Uniform flow (e.g. drain)
Moderately varied flow
Varied flow (eg eddies, backwaters, fast, slow)

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)

Version 12 - November 2009 Page 5 of 19

Date ______________ Site code ______________

Government of Western Australia
Department of Water

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

Version 12 - November 2009 Page 6 of 19

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): ________________________________

Version 12 - November 2009 Page 7 of 19

Date ______________ Site code ______________

Government of Western Australia
Department of Water

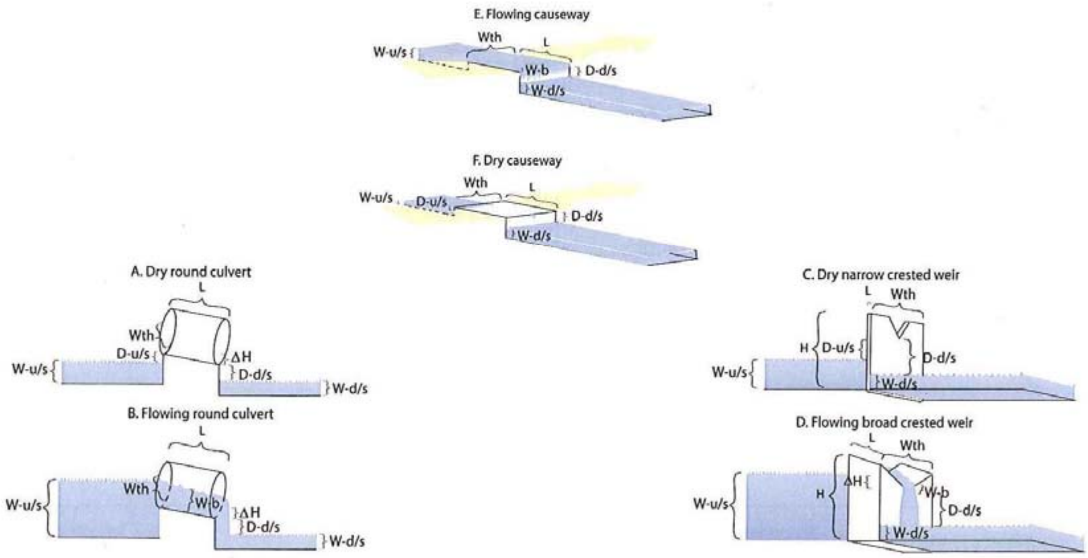
SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
BARRIER ASSESSMENT - 100m sampling site

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.



Version 12 - November 2009 Page 8 of 19

Date ________________ Site code ________________

Government of Western Australia
Department of Water

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 ________________________________

Version 12 - November 2009 Page 9 of 19

Date ______________ Site code ______________

Government of Western Australia
Department of Water

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

Version 12 - November 2009 Page 10 of 19

Date ________________ Site code ________________

Government of Western Australia
Department of Water

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 ______________________

Version 12 - November 2009 Page 11 of 19

Date _______________ Site code _______________

Government of Western Australia
Department of Water

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						

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)

NOTE: In most cases salinity and temperature are not calibrated prior to use.

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

Version 12 - November 2009 Page 12 of 19

Date ________________ Site code ________________

Government of Western Australia
Department of Water

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

____

Version 12 - November 2009

Page 13 of 19

Date ________________ Site code ________________

Government of Western Australia
Department of Water

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.

Version 12 - November 2009 Page 14 of 19

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)

____

____

Version 12 - November 2009 Page 19 of 19

Appendix C — System-scale flow observations

8 February 2011

15 February 2011

16 February 2011

17 February 2011

18 February 2011

19 February 2011

21 February 2011

22 February 2011

Figure C1 Upper site, pool, looking upstream (8 to 22 February 2011)

23 February 2011

15 March 2011

24 February 2011

11 April 2011

25 February 2011

9 May 2011

Figure C2 Upper site, pool, looking upstream (23 February to 9 May 2011)

8 February 2011

8 February 2011

15 February 2011

19 February 2011

16 February 2011

21 February 2011

17 February 2011

22 February 2011

Figure C3 Upper site, riffle, looking upstream (8 to 22 February 2011)

23 February 2011

15 March 2011

25 February 2011

11 April 2011

9 May 2011

Figure C4 Upper site, riffle, looking upstream (23 February to 9 May 2011)

19 February 2011

15 March 2011

24 February 2011

No image

11 April 2011

9 May 2011

Figure C5 Flow site 1, riffle, looking across the stream

19 February 2011

No image

24 February 2011

15 March 2011

11 April 2011

9 May 2011

Figure C6 Flow site 1, riffle, looking upstream

19 February 2011

No image

15 March 2011

24 February 2011

11 April 2011

9 May 2011

Figure C7 Flow site 1, riffle, looking downstream

16 February 2011

15 March 2011

19 February 2011

11 April 2011

21 February 2011

9 May 2011

Figure C8 Flow site 2, run, looking upstream

16 February 2011

15 March 2011

19 February 2011

11 April 2011

21 February 2011

9 May 2011

Figure C9 Flow site 2, run, looking downstream at rock riffle

16 February 2011

No image

15 March 2011

19 February 2011

No image

11 April 2011

21 February 2011

9 May 2011

Figure C10   Flow site 2, shallow pool, looking upstream towards rock riffle

16 February 2011

19 February 2011

21 February 2011

15 March 2011

11 April 2011

9 May 2011

Figure C11 Flow site 2, shallow pool, looking downstream

8 February 2011

18 February 2011

14 February 2011

19 February 2011

16 February 2011

21 February 2011

17 February 2011

22 February 2011

Figure C12 Lower site, riffle, looking upstream (8 to 22 February 2011)

23 February 2011

15 March 2011

24 February 2011

11 April 2011

25 February 2011

No image

9 May 2011

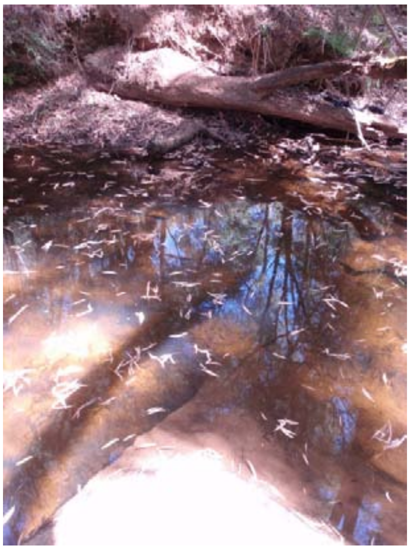
Figure C13 Lower site, riffle, looking upstream (23 February to 9 May 2011)

8 February 2011

No image

14 February 2011

16 February 2011



17 February 2011

No image

18 February 2011

19 February 2011

No image

21 February 2011

No image

22 February 2011

Figure C14 Lower site, run, looking across the stream (8 to 22 February 2011)

23 February 2011

No image

15 March 2011

24 February 2011

No image

11 April 2011

25 February 2011

No image

9 May 2011

Figure C15 Lower site, run, looking across the upstream (23 February to 9 May 2011)

8 February 2011

No image

18 February 2011

14 February 2011

19 February 2011

No image

16 February 2011

21 February 2011

17 February 2011

22 February 2011

Figure C16 Lower site, pool, looking upstream (8 to 22 February 2011)

23 February 2011

15 March 2011

24 February 2011

11 April 2011

25 February 2011

9 May 2011

Figure C17 Lower site, pool, looking upstream (23 February to 9 May 2011)

Appendix D — Water quality results

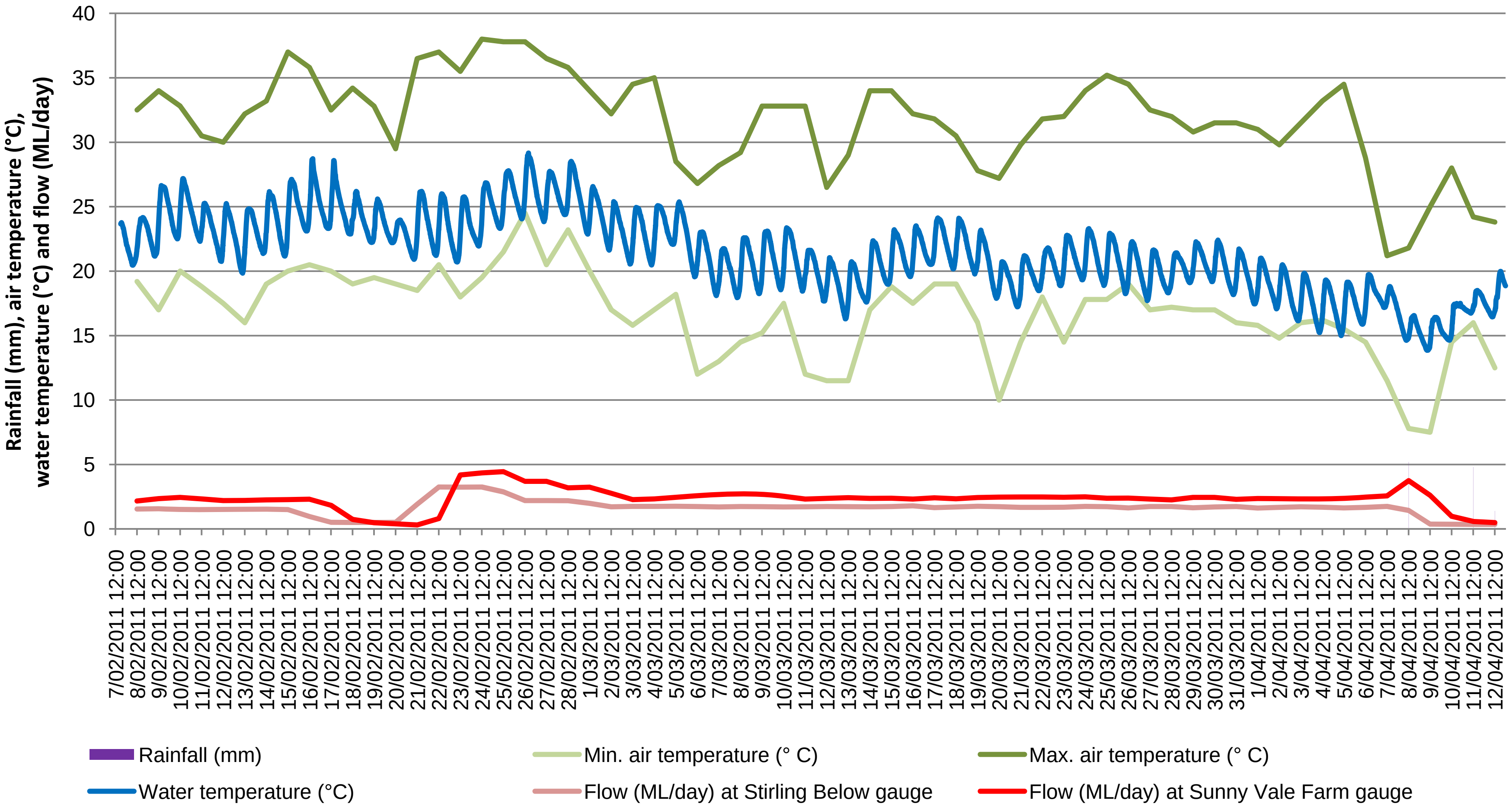


Figure D1 Water temperature (degrees centigrade) at the upper site, flow (megalitres/day) at Stirling Below and Sunny Vale Farm gauges, rainfall (millimetres) and air temperature (degrees centigrade) at Harvey meteorological station

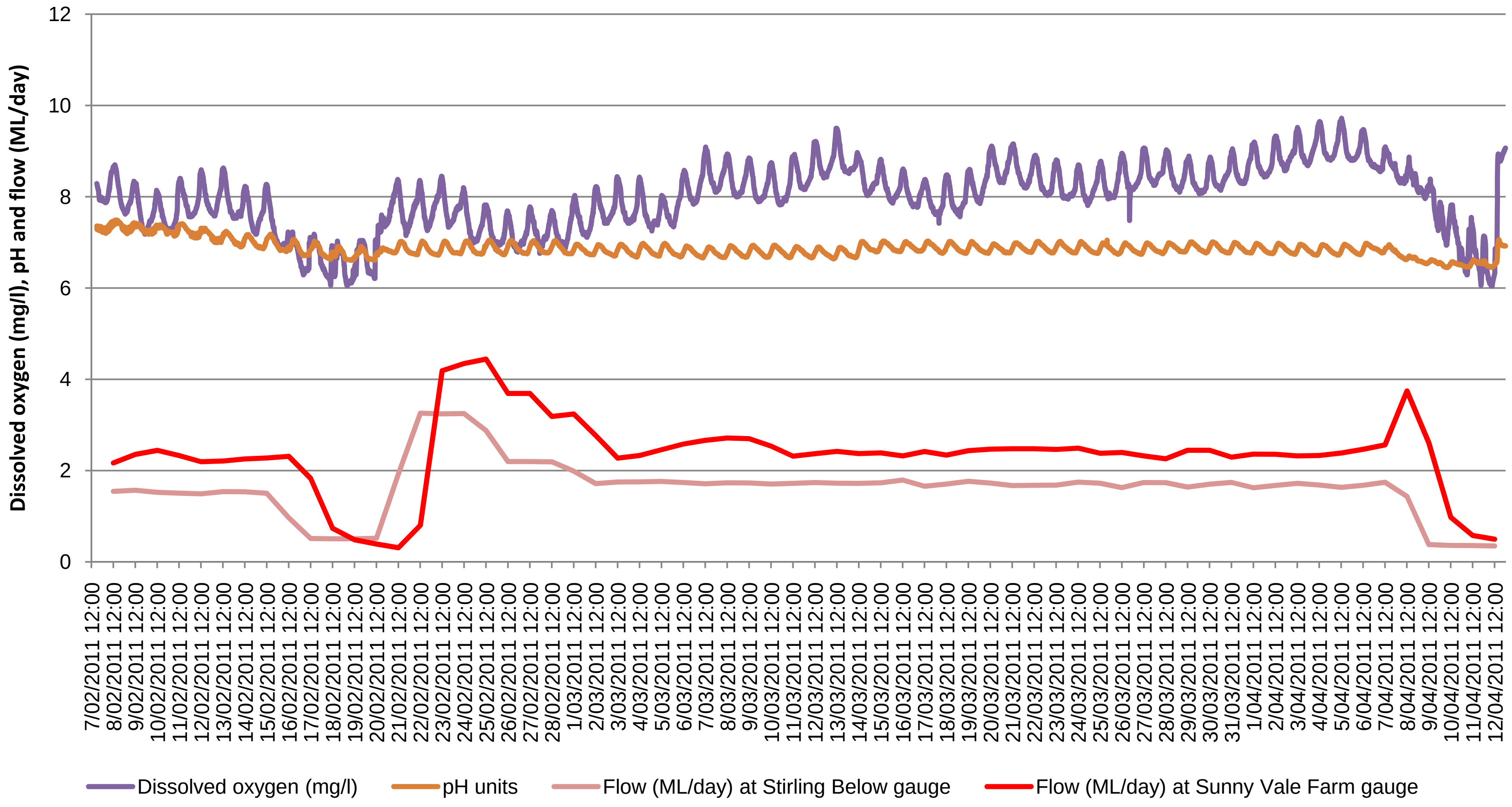


Figure D2 Dissolved oxygen (milligrams/litre)and pH at the upper site; flow (megalitres/day) at Stirling Below and Sunny Vale Farm gauges

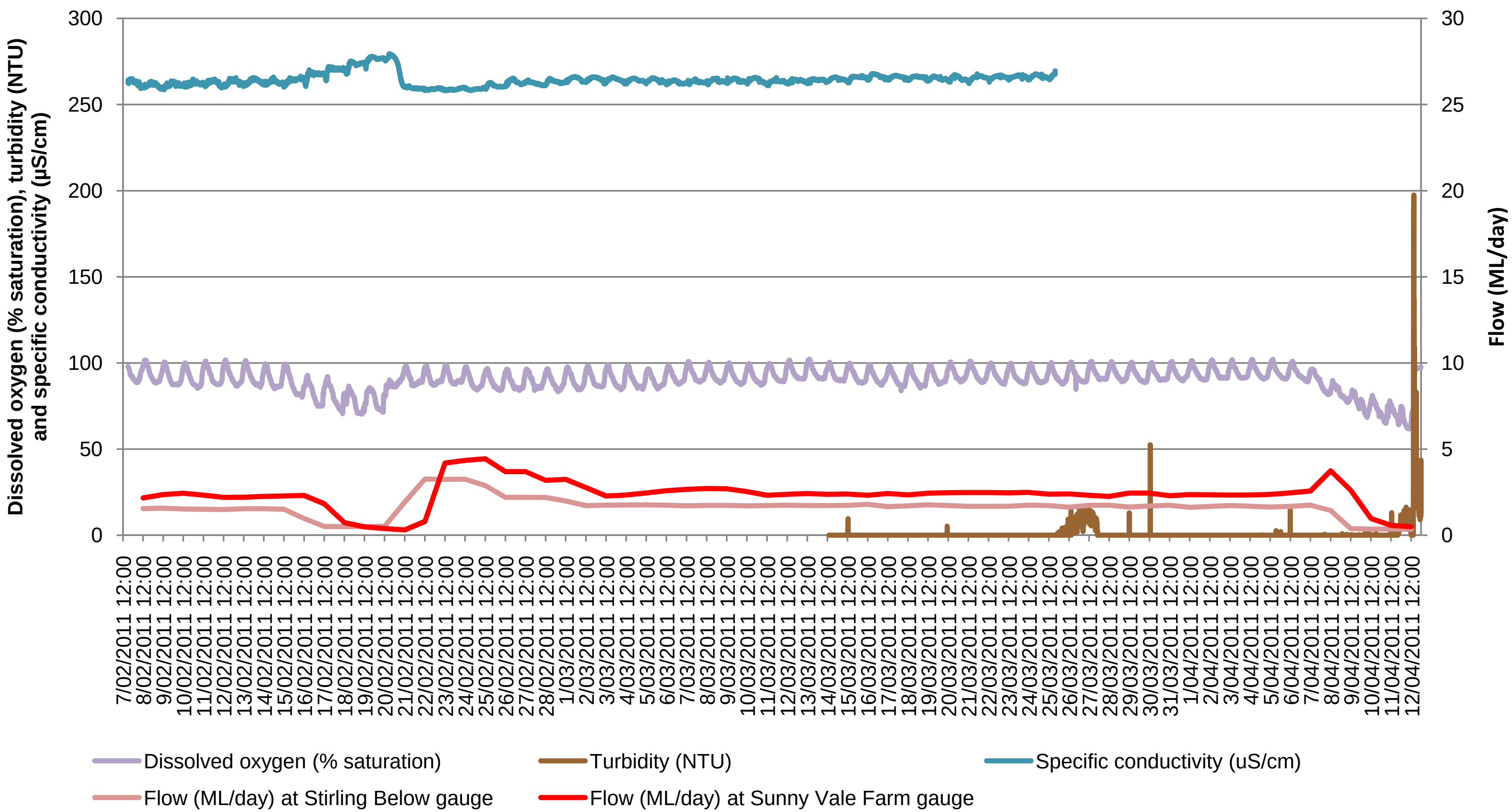


Figure D3 Dissolved oxygen (% saturation), turbidity (NTU) and specific conductivity (microSiemens/cm) and pH at the upper site; flow (megalitres/day) at Stirling Below and Sunny Vale Farm gauges

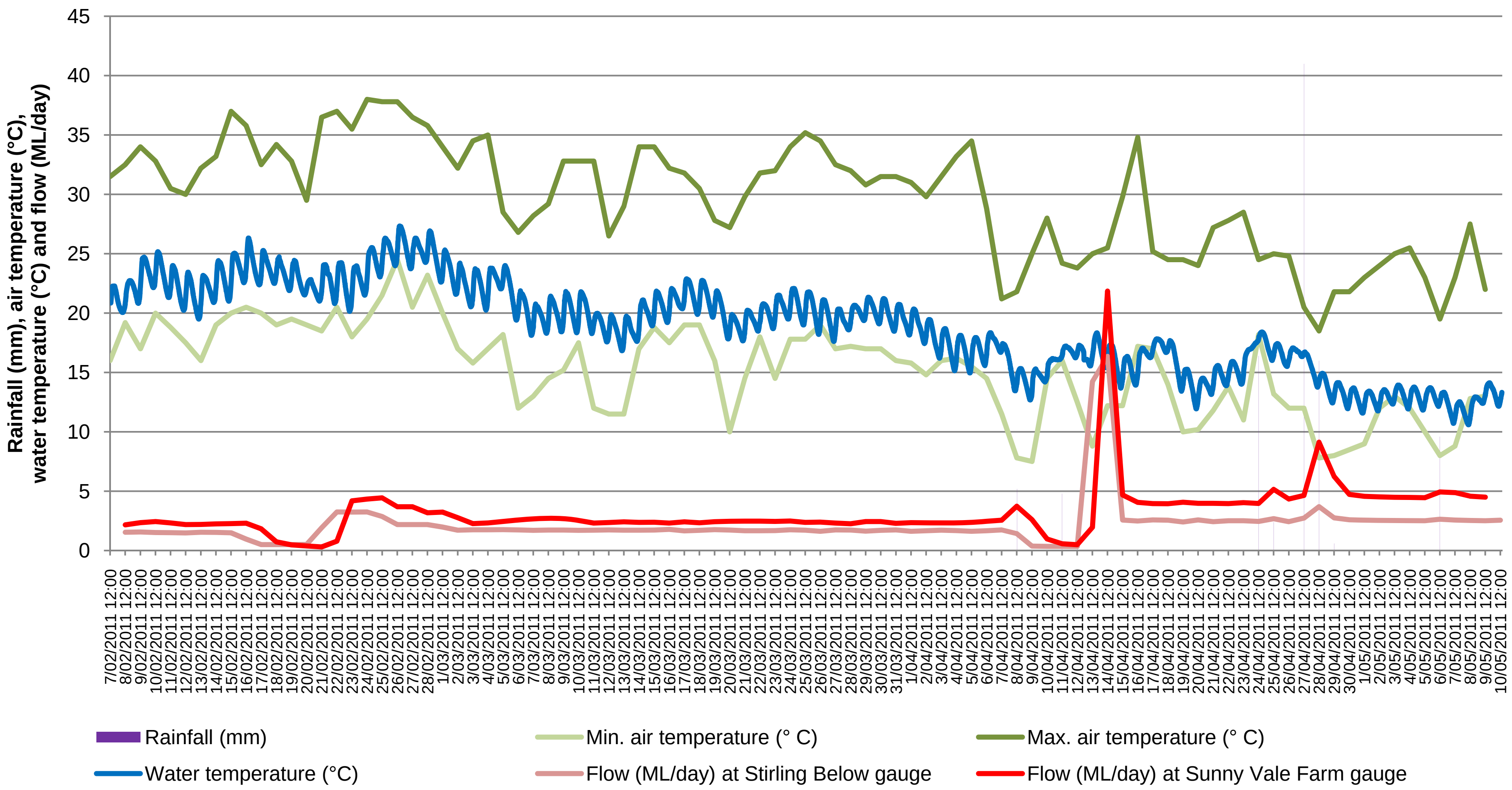


Figure D4 Water temperature (degrees centigrade) at the lower site, flow (megalitres/day) at Stirling Below and Sunny Vale Farm gauges, rainfall (millimetres) and air temperature (degrees centigrade) at Harvey meteorological station

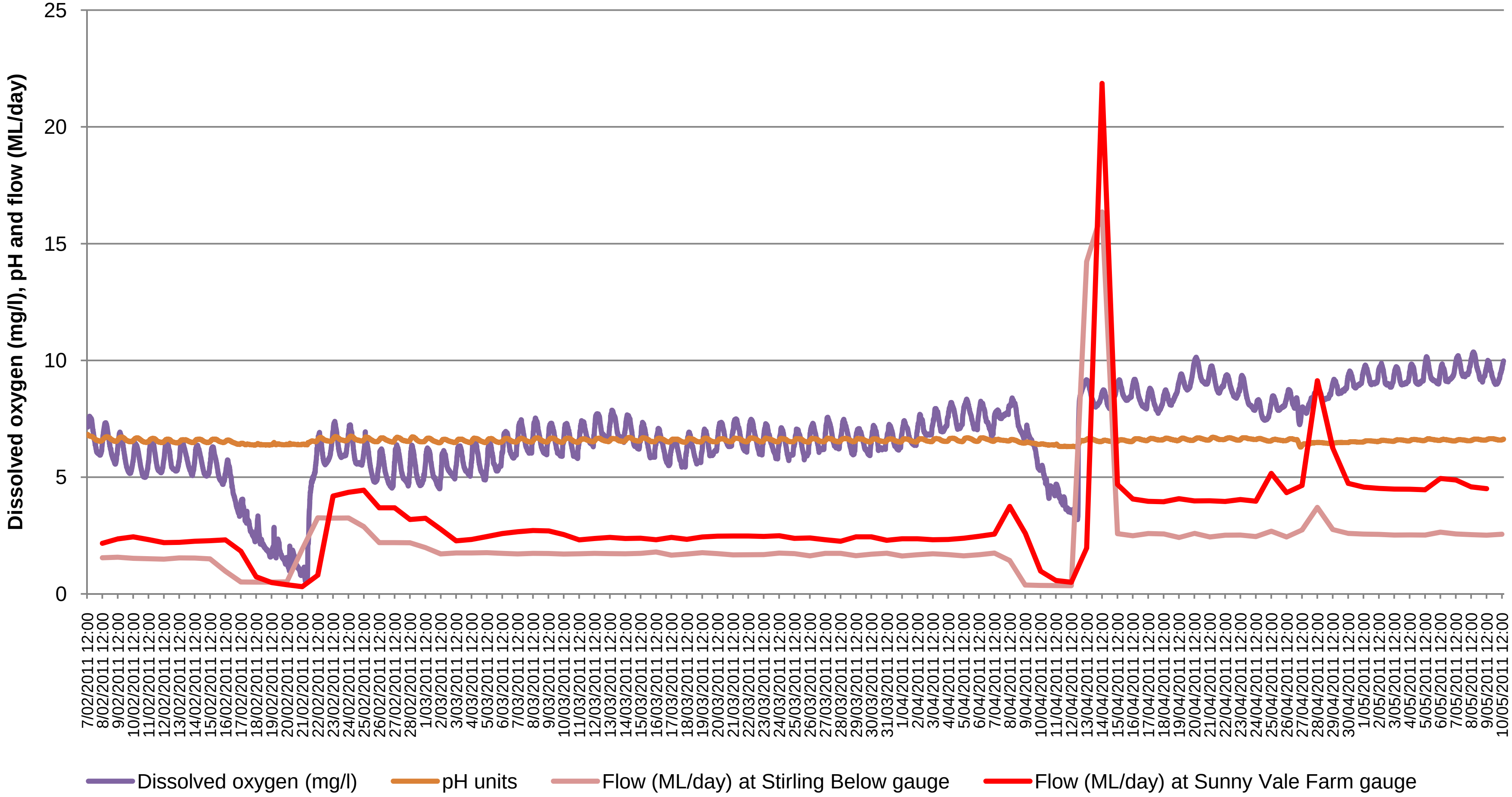


Figure D5 Dissolved oxygen (milligrams/litre)and pH at the upper site and flow (megalitres/day) at Stirling Below and Sunny Vale Farm gauges

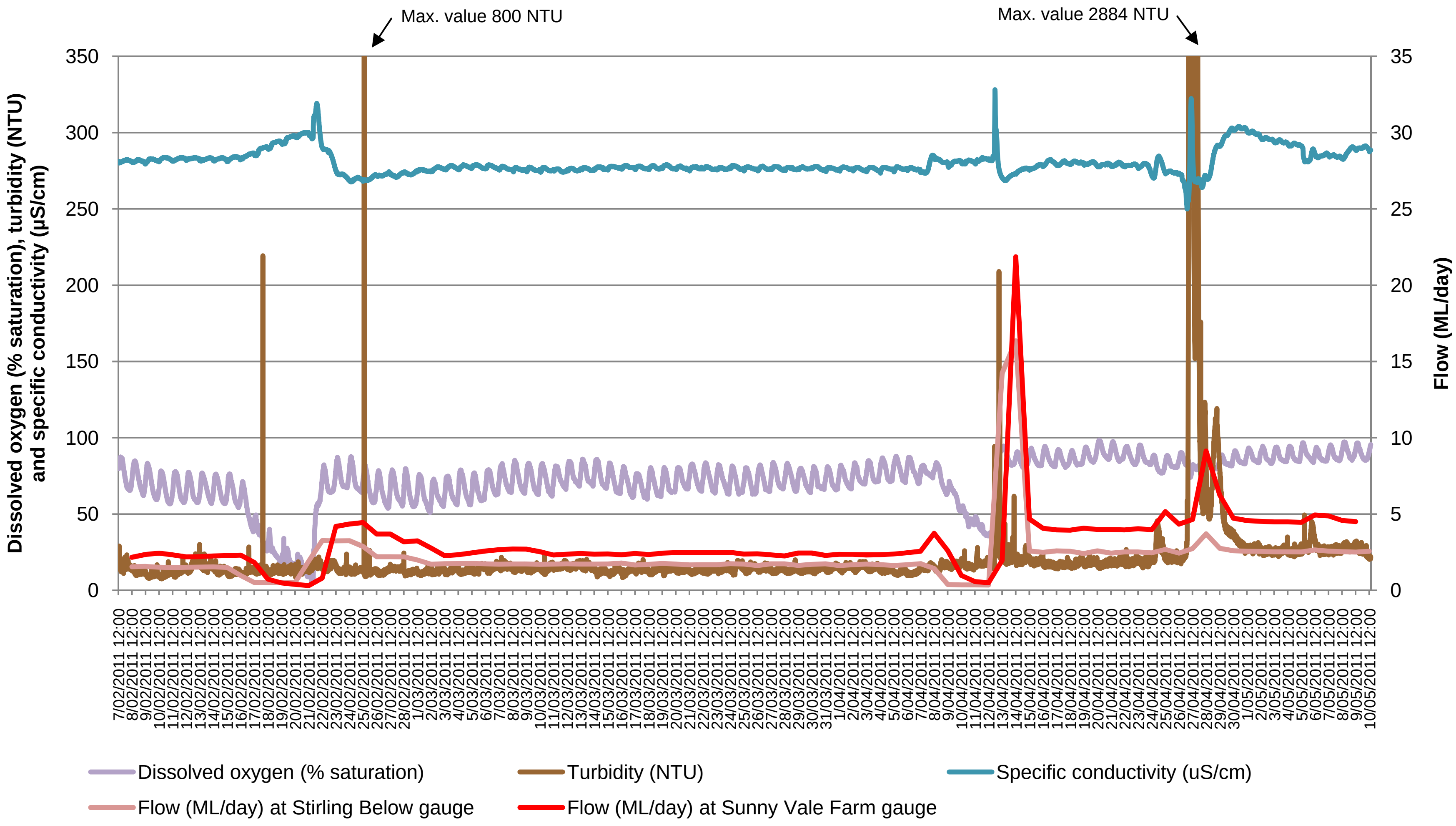


Figure D6 Dissolved oxygen (% saturation), turbidity (NTU) and specific conductivity (microSiemens/cm)and pH at the upper site and flow (megalitres/day) at Stirling Below and Sunny Vale Farm gauges

Table D1 Water quality results for the lower site during distinct periods of the study

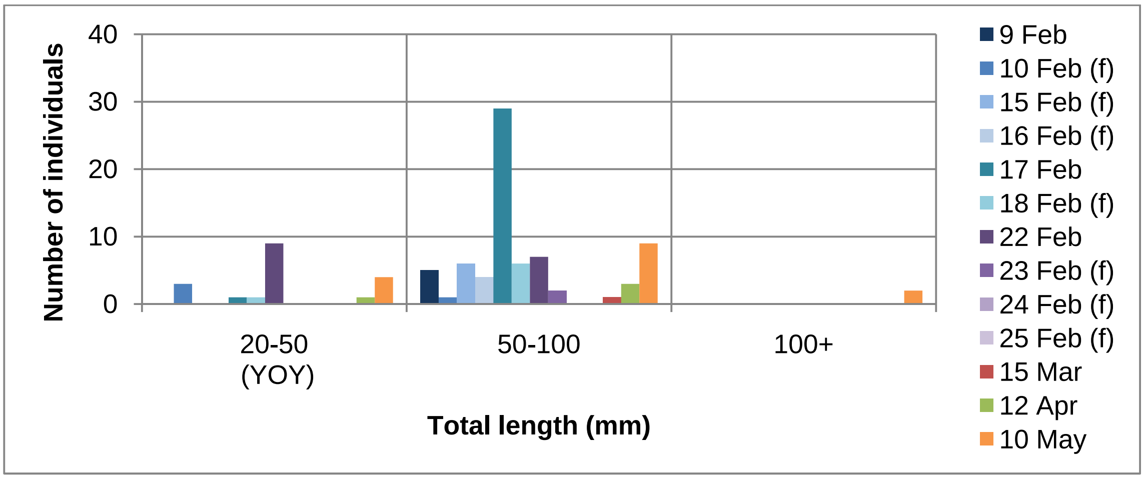
Period		ODO (mg/l)	ODO (% sat)	Turbidity (NTU)	Temperature (deg C)	Specific conductivity (uS/cm)	pH	Flow (ML/day)
Whole of study	**Min**	0.5	5.6	7.5	10.6	250.0	6.3	0.3
	Max	10.4	98.4	2884.0	27.3	328.1	6.8	21.9
	Mean	**6.8**	**72.5**	**25.4**	**18.8**	**280.3**	**6.6**	**3.2**
	St Dev	1.8	16.0	117.2	3.8	7.8	0.1	2.4
Pre-trial	**Min**	5.0	56.7	7.5	19.5	279.4	6.5	2.2
(~2 ML/day)	**Max**	7.6	87.4	30.1	25.2	283.7	6.8	2.4
7/2 - 14/2	**Mean**	**6.0**	**68.9**	**13.0**	**22.3**	**282.3**	**6.6**	**2.3**
(8 days)	**St Dev**	0.6	8.0	3.1	1.4	0.9	0.1	0.1
No-release trial	**Min**	0.5	5.6	8.7	21.0	281.0	6.4	0.3
15/2 - 21/2	**Max**	6.3	76.3	219.3	26.3	312.1	6.6	2.3
(7 days)	**Mean**	**3.1**	**36.2**	**12.8**	**23.2**	**290.9**	**6.4**	**1.2**
	St Dev	1.6	19.7	6.8	1.2	6.7	0.1	0.9
Recovery period	**Min**	4.2	49.2	9.0	20.2	267.7	6.5	0.8
22/2 - 5/3	**Max**	7.4	87.6	800.1	27.3	319.1	6.8	4.4
(12 days)	**Mean**	**5.6**	**66.7**	**13.4**	**23.7**	**276.1**	**6.6**	**3.1**
	St Dev	0.7	8.4	19.0	1.7	8.0	0.1	1.1
Minimal flow	**Min**	5.3	58.7	8.3	13.5	273.3	6.5	2.3
between trial	**Max**	8.4	87.8	22.8	22.9	285.2	6.7	3.7
and works	**Mean**	**6.7**	**73.2**	**13.9**	**19.4**	**276.6**	**6.6**	**2.5**
6/3 - 8/4	**St Dev**	0.6	6.6	1.9	1.7	1.4	0.1	0.3
WC works	**Min**	3.2	32.8	13.3	12.7	277.2	6.3	0.5
09/4 - 12/4	**Max**	7.9	80.3	94.3	17.3	328.1	6.5	2.6
(4 days)	**Mean**	**5.1**	**51.4**	**17.2**	**15.6**	**281.7**	**6.4**	**1.2**
	St Dev	1.3	11.9	5.4	1.3	4.7	0.1	1.0
Recovery period	**Min**	7.7	80.5	14.1	13.4	268.5	6.5	2.0
13/4 - 19/4	**Max**	9.4	94.5	208.9	18.3	313.4	6.7	21.9
(7 days)	**Mean**	**8.5**	**86.5**	**19.5**	**16.2**	**278.0**	**6.6**	**6.4**
	St Dev	0.4	4.0	8.1	1.2	4.9	0.0	6.9
Minimal flow	**Min**	7.3	74.1	14.4	10.6	250.0	6.3	4.0
after works	**Max**	10.4	98.4	2884.0	18.4	322.3	6.7	9.1
20/4 to end	**Mean**	**9.0**	**86.9**	**63.4**	**14.0**	**285.1**	**6.6**	**4.8**
	St Dev	0.6	4.6	242.5	1.8	10.4	0.1	1.1

** flow recorded at Sunny Vale Farm gauge*

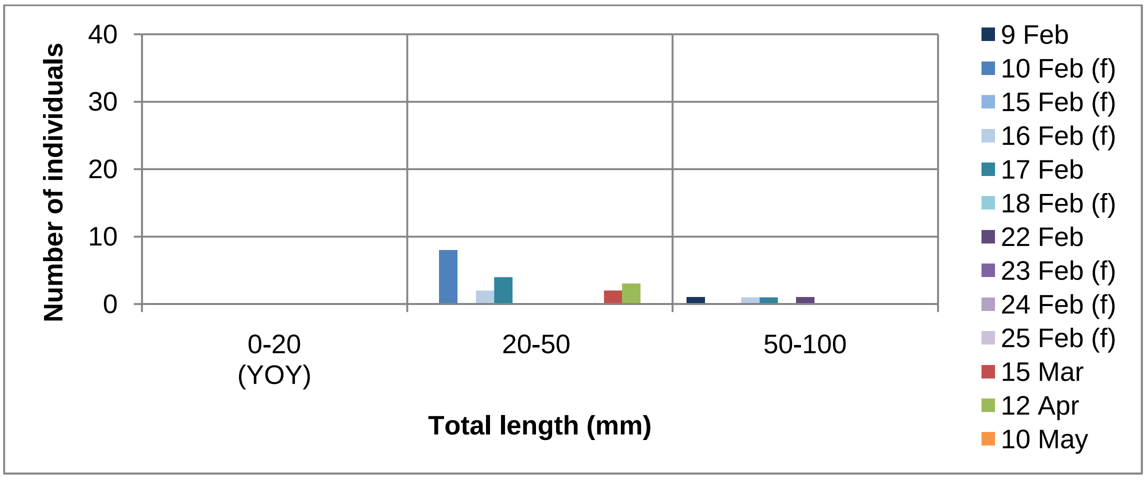
Appendix E — Size distribution of fish and crayfish

Upper site

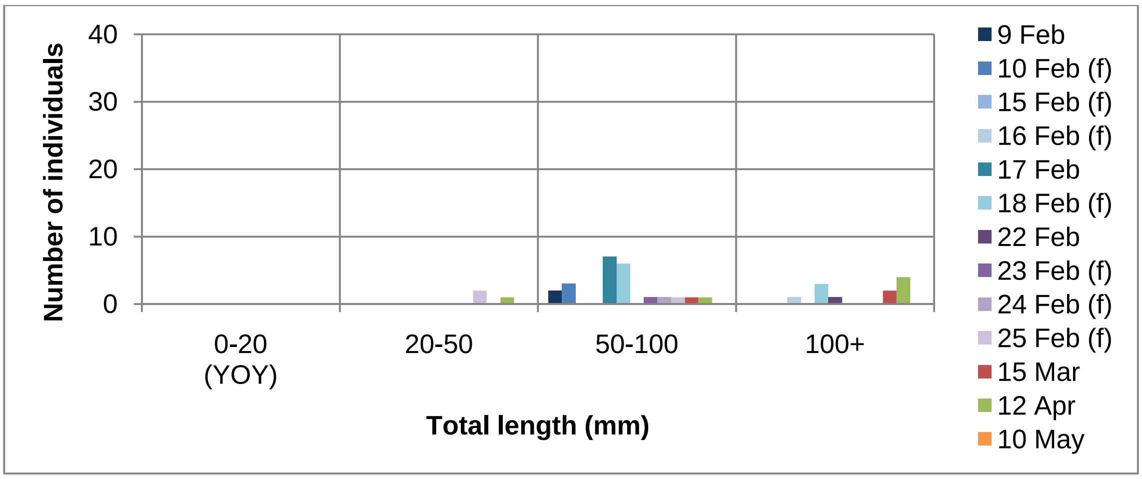
Western minnow (*G. occidentalis*)



Western pygmy perch (*E. vittata*)

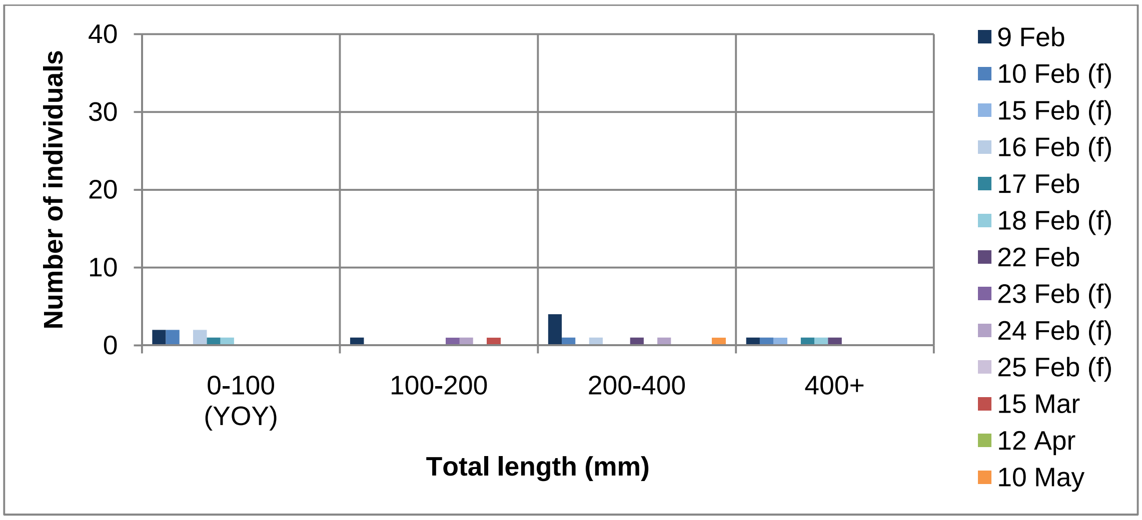


Nightfish (*B. porosa*)

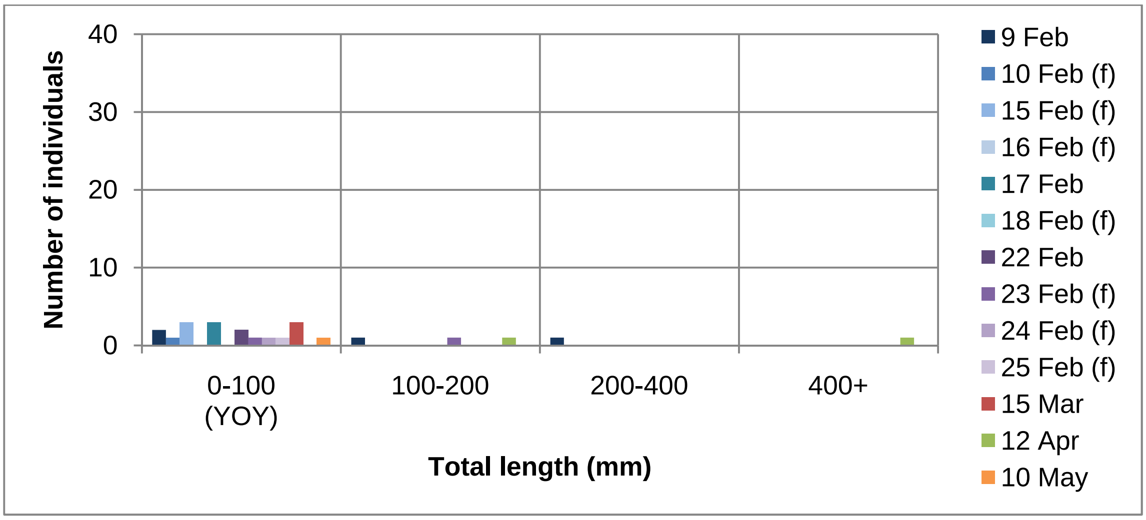


Note: f = fyke nets only

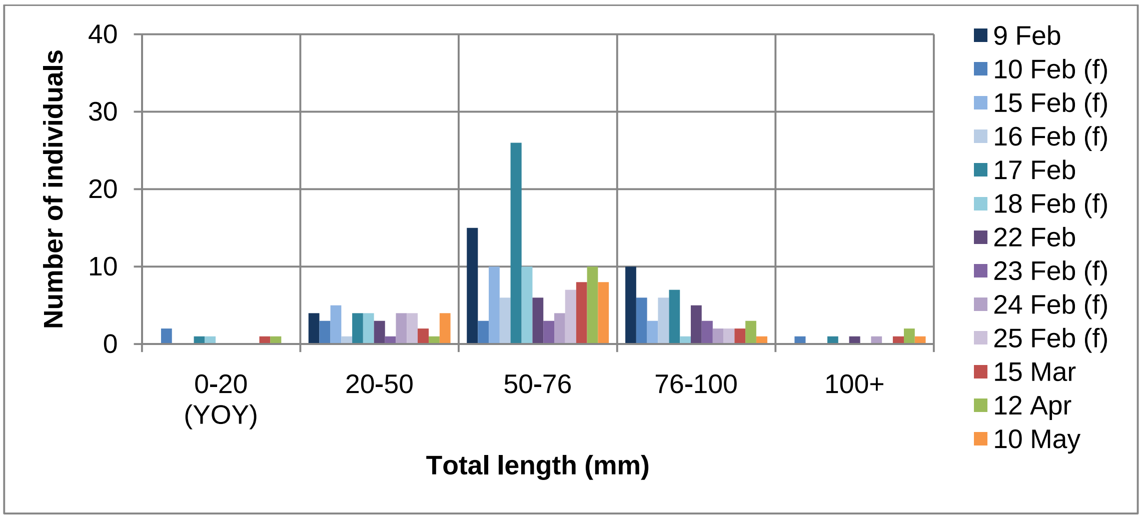
Freshwater cobbler (*T. bostocki*)



Redfin perch (*P. fluviatilis*)

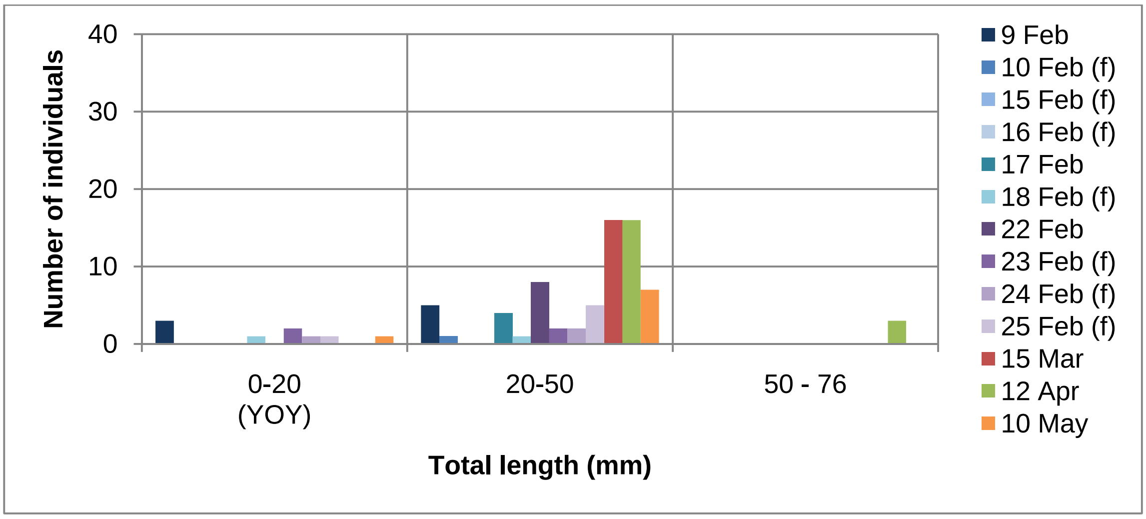


Smooth marron (*C. cainii*)



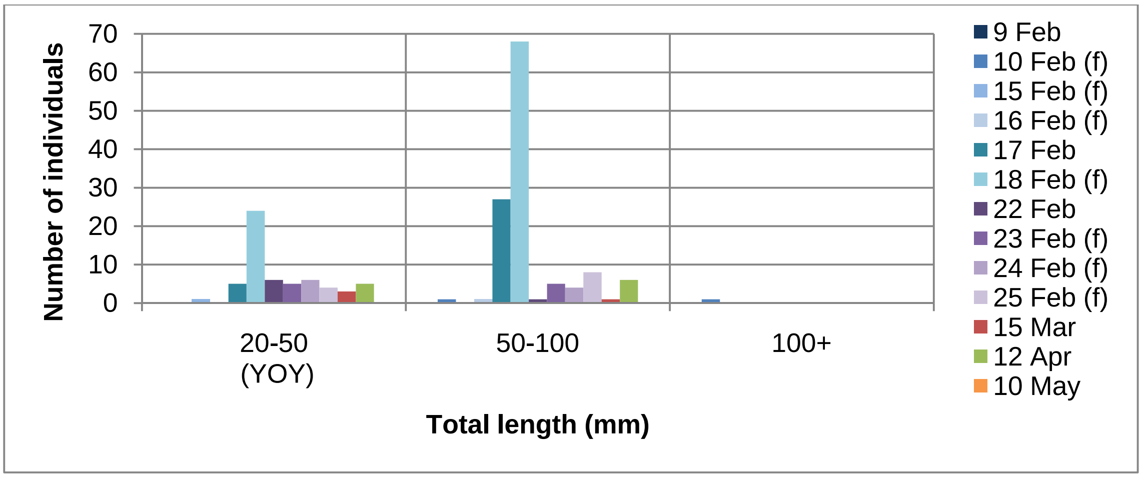
Note: f = fyke nets only

Gilgie (*C. quinquecarinatus*)

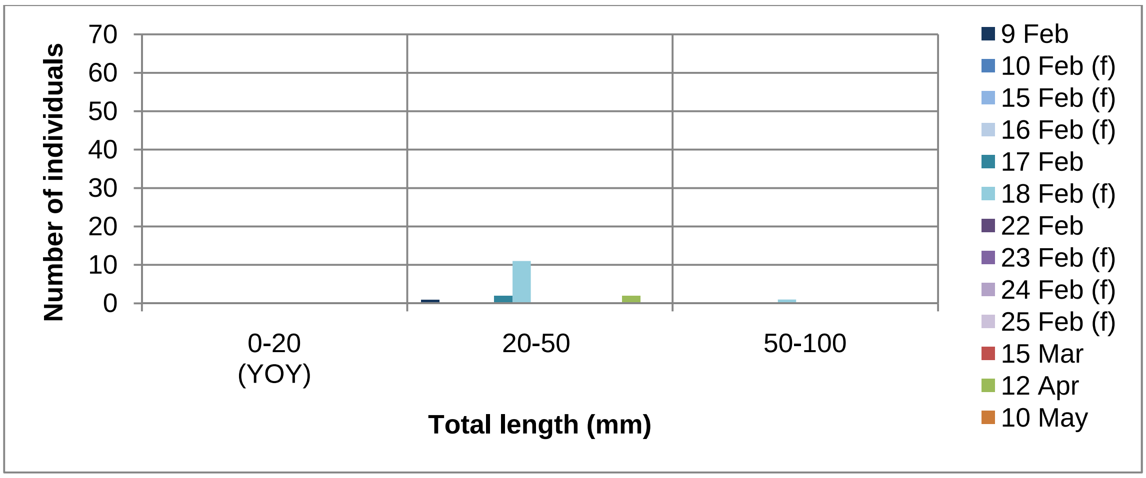


Lower site

Western minnow (*G. occidentalis*)

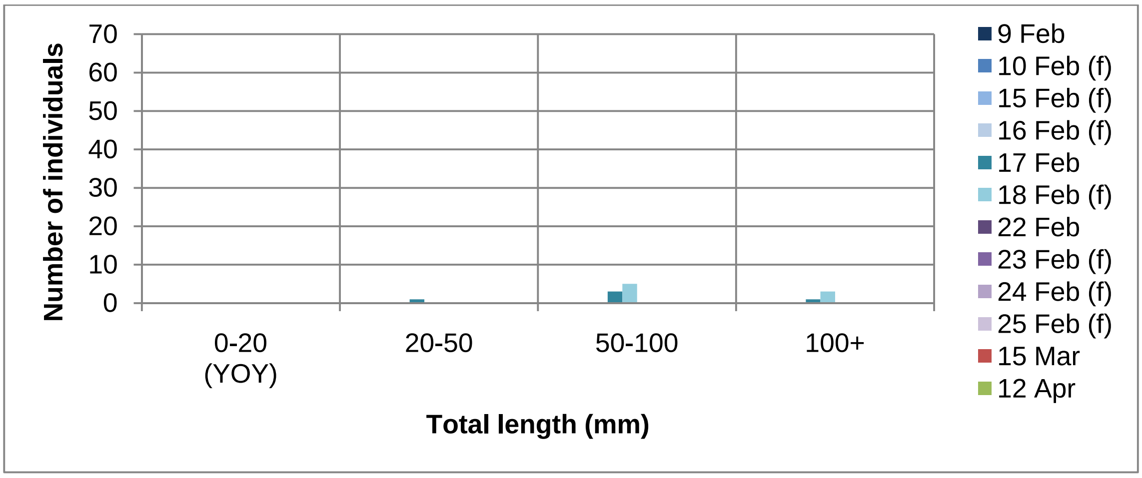


Western pygmy perch (*E. vittata*)

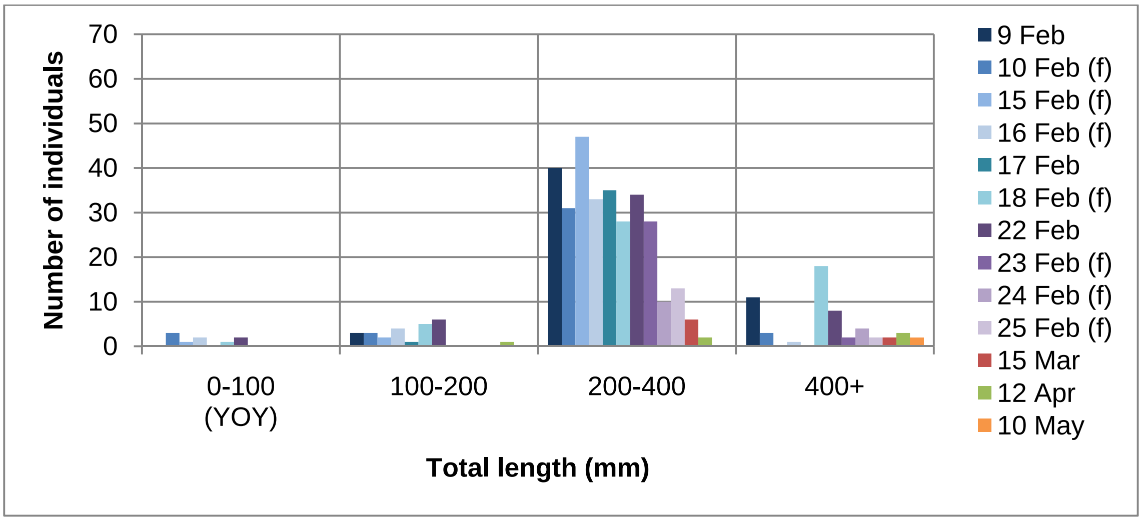


Note: f = fyke nets only

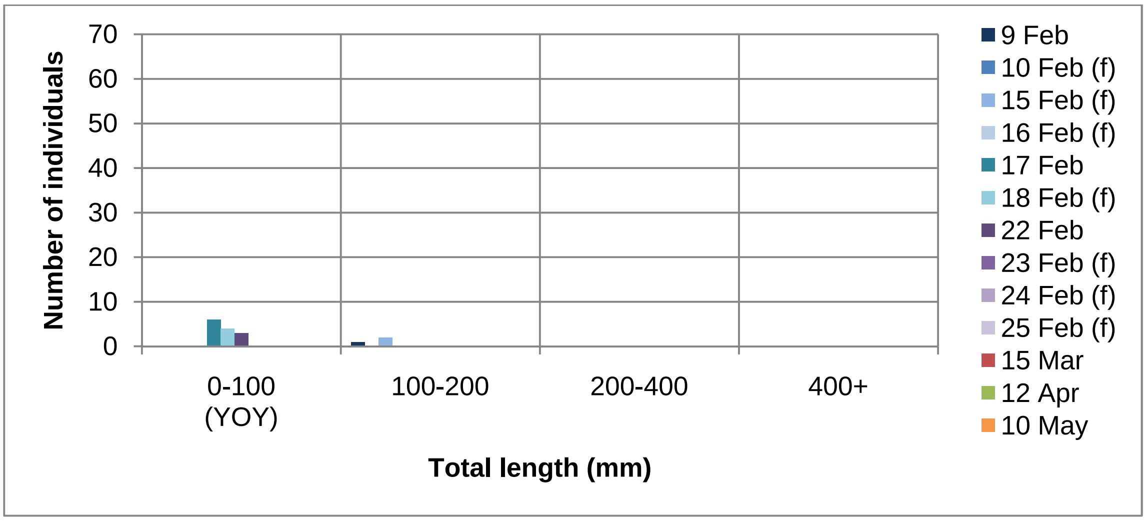
Nightfish (*B. porosa*)



Freshwater cobbler (*T. bostocki*)

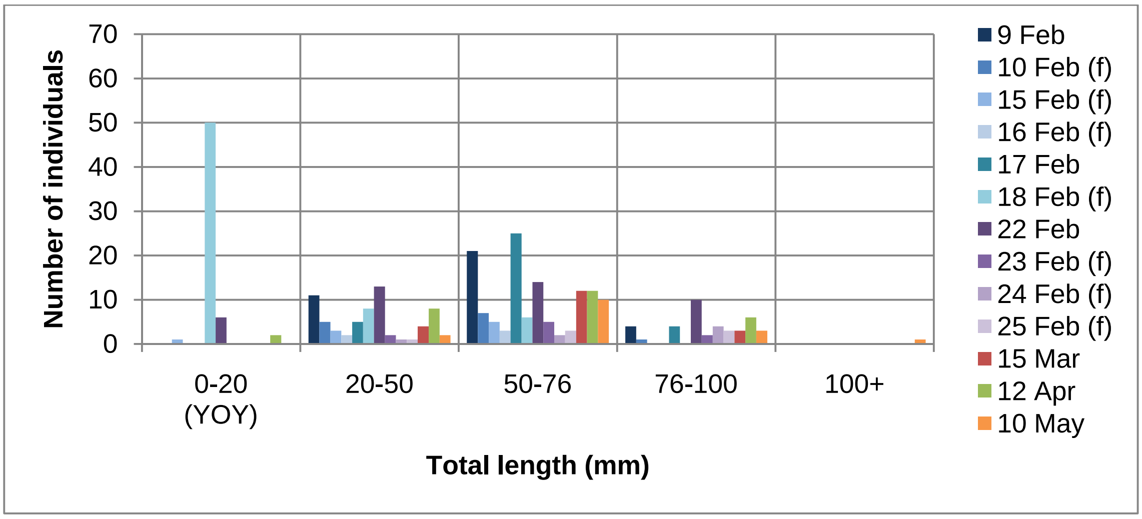


Redfin perch (*P. fluviatilis*)

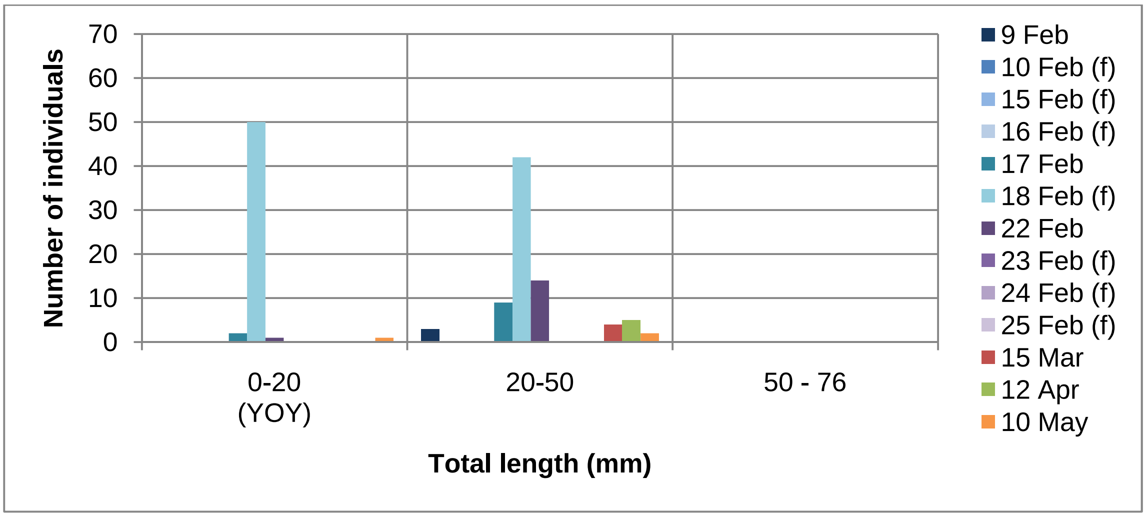


Note: f = fyke nets only

Smooth marron (*C. cainii*)



Gilgie (*C. quinquecarinatus*)



Note: f = fyke nets only

Appendix F — Response protocol (following a breach of the flow threshold)

If the daily flow, recorded at Sunny Vale Farm gauge, falls below 2.7 ML/day, it is recommended that the following monitoring response be initiated:

1. Monitoring of dissolved oxygen should begin:
    a. Spot readings of dissolved oxygen should be taken in the two pools downstream from the Sunny Vale Farm gauging station (Figure 7).
    b. Readings should be taken at one location in each pool, at the deepest point accessible from the bank. Readings should be taken at 20 cm-depth intervals (starting from 10 cm below the water surface and ending just above the sediment at the bottom of the pool) to create a profile of dissolved oxygen through the water column. The water temperature and time of each reading should also be recorded.
    c. Readings should be taken once every two days, at approximately the same time of day. If possible, readings should be taken early in the morning to ensure that values represent the lower end of the diurnal range.
2. If dissolved oxygen levels of less than 5 mg/L are recorded in the pools, the Department of Water's Environmental Water Planning Section should be informed. An appropriate course of action will be agreed between the Department of Water and Water Corporation: this may include increasing the frequency or spatial coverage of monitoring, or increasing water releases to provide more flow.
3. Monitoring should continue until the dissolved oxygen is above 5 mg/L, unless otherwise agreed with the Department of Water.

Appendix G — Map disclaimer and data acknowledgements

The maps in this publication were produced by the Department of Water with the intent that they be used as illustrations in this report *Assessment of ecological health and environmental water provisions in the Harvey River (between Stirling Dam and Harvey Reservoir)*, *February to May 2011*. 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 analysis of data and production of the maps:

Dataset Name	Custodian acronym	Metadata year
Hydrography, linear (hierarchy)	DOW	2007
Water dam area	WC	n/a
Road centrelines	Landgate	2010
Western Australian towns	Landgate	2001
WA Coastline	DOW	2006
Water Information Network sites	DOW	2006
Land use in Western Australia, version 2	DAFWA	2001
1 second SRTM derived digital elevation model (DEM) v1.0	GA	2009
Collie 2006 50cm z50	Landgate	2009
Bunbury 2006 50cm z50	Landgate	2009

The maps have been produced using the following data and projection information:

Vertical Datum: AHD (Australian Height Datum)

Horizontal Datum: GDA 94 (Geocentric Datum of Australia 1994)

Projection System: Map Grid of Australia (MGA) 1994 Zone 50

Original ArcMap documents (*.mxd):
J:\gisprojects\Project\B_Series\B5047\000_related_tasks\011_Harvey_Logue\mxds

Shortened forms

ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BoM	Bureau of Meteorology
CEAH	Centre of Environmental Applied Hydrology
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAFWA	Department of Agriculture and Food Western Australia
DEM	digital elevation model
DoE	Department of Environment (former)
DoW	Department of Water
EWP	environmental water provision
EWR	ecological water requirement
FARWH	Framework for the Assessment of River and Wetland Health
GA	Geoscience Australia
IOCI	Indian Ocean Climate Initiative
IWSS	Integrated Water Supply System
MDRFC	Murray Darling Freshwater Research Centre
NTU	nephelometric turbidity units
NWC	National Water Commission
ODO	optical dissolved oxygen
SRTM	Shuttle Radar Topography Mission
SWIRC	South-West Index of River Condition
SWWA	South-West Western Australia
WC	Water Corporation
WEC	Welker Environmental Consultancy
WRC	Waters and Rivers Commission (former)
WRM	Wetland Research and Management
WRMOS	water resource management operating strategy
YOY	young of year

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.
Allochthonous source	A source of organic matter that arises from outside the waterway e.g. leaf litter, woody debris.
Autochthonous source	A source of organic matter that arises from within the waterway e.g. macrophytes, phytoplankton, periphyton.
Baseline data	Data representing the existing elements, characteristics and trends in an area to provide a measure against which change can be assessed.
Berried	Bearing eggs.
Biota	Living things e.g. flora and fauna.
Carapace (freshwater crayfish)	Protective shell covering the head and thorax of freshwater crayfish.
Confluence	Running together, flowing together; such as where a tributary joins a river.
Diel	Relating to 24 hour period.
Dissolved oxygen	The concentration of oxygen dissolved in water or effluent, measured in milligrams per litre (mg/L) or % saturation.
Diurnal cycle	A pattern that recurs every 24 hours.
Ecological health	The extent to which ecological processes and functions are resilient and adaptive, giving rise to self-regulation, stability and diversity in populations and ecosystems.
Ecological values (of a waterway)	The natural ecological processes occurring within water-dependent ecosystems and the biodiversity of these systems.
Ecological water requirements	The water regime needed to maintain the ecological values (including assets, functions and processes) of water-dependent ecosystems at a low level of risk.

Ecological water provision	The water regime provided as a result of the water allocation decision-making process taking into account ecological, social and economic values. It may meet in part or in full the ecological water requirements.
Ecosystem	A community or assemblage of communities of organisms, interacting with one another, and the specific environment in which they live and with which they also interact (e.g. a lake). Includes all the biological, chemical and physical resources and the interrelationships and dependencies that occur between those resources.
Ectoparasite	A parasite that lives on the exterior of another organism.
Endemic species	Unique to a particular geographic location.
Epiphyte	A plant or other organism that lives on the surface of plants without deriving nutrition from them.
Flow	Streamflow; may be measured as m^3/yr, m^3/d or ML/yr. May also be referred to as discharge.
Grab sample	Manual water sample obtained in a bottle for the purpose of analysing its water quality. Usually taken in flowing water just below, but not touching the surface.
Gravid	The condition of a fish when carrying eggs internally.
Habitat	The environment or place where a plant or animal naturally or normally grows or lives (includes soil, water, climate, other organisms and communities).
Interstitial space	An opening or space, especially a small or narrow one, within sediments or soil.
Macrophyte (aquatic)	Rooted aquatic plants e.g. eelgrass.
Native species	A species occurring in a region or ecosystem as a result of natural processes only.
Nuptial colours	Colouring relating to mating or occurring during the mating season.

pH	A symbol denoting the logarithmic concentration of hydrogen (H) ions in solution. A measure of acidity or alkalinity in water in which pH 7 is neutral, values above 7 are alkaline and values below 7 are acid.
Refugia (in a waterways)	Sections of a stream that provide habitat and sufficient water quality and quantity to preserve aquatic biota during low-flow periods.
Riparian vegetation	Vegetation growing along banks of watercourses, including the brackish upstream reaches of estuaries.
Species richness	Number of species in a sample or population.
Substrate (in a waterway)	Physical substrate: the silt, sand and stone components of the streambed; biological substrate: organic matter such as woody debris, sticks, leaves and decomposing matter.
Surface water	Water flowing or held in streams, rivers and other wetlands on the surface of the landscape.
Turbidity	Opaqueness of water due to suspended particles in the water causing a reduction in the transmission of light. The units of measurement are NTU (nephelometric turbidity units).
Urogenital papillae	A small tube near the anus through which eggs or sperm are released.
Water Corporation	A government-owned organisation that supplies water, wastewater and drainage services in Western Australia.
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.
Water resource management operating strategy	A signed agreement between a licensee and the Department of Water regarding the management of specific water resources.
Young of year	Animals born within the past year.

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)

Species list

Aquatic fauna collected or observed during this study or previous studies

Common name	**Latin name**	**Organism type**	**Native or non-native (or distribution)**
Freshwater cobbler	*Tandanus bostocki*	Fish	Native [3]
Mosquitofish	*Gambusia holbrooki*	Fish	Non-native
Nightfish	*Bostockia porosa*	Fish	Native
Redfin perch	*Perca fluviatilis*	Fish	Non-native
Swan River goby	*Psuedogobius olorum*	Fish	Native
Western minnow	*Galaxias occidentalis*	Fish	Native
Western pygmy perch	*Nannoperca vittata* [1]	Fish	Native
Gilgie	*Cherax quinquecarinatus*	Crayfish	Native
Smooth marron	*Cherax cainii*	Crayfish	Native
Yabbie	*Cherax* sp. *(yabbie)* [2]	Crayfish	Non-native
Water rat	*Hydromys chrysogaster*	Mammal	Native [4]
Caddisfly larvae	*Oecetis* sp.	Macroinvertebrate	Australia wide [5]
Diving beetle larvae	*Dytiscidae* spp	Macroinvertebrate	Australia wide
Dragonfly larvae	*Austrogomphus* sp. and *Anisoptera* spp.	Macroinvertebrate	Australia wide
Freshwater shrimp	*Palaemontes australis*	Macroinvertebrate	Australia wide
Mayfly nymph	*Tasmanocoenis* sp.	Macroinvertebrate	Australia wide
Midge larvae	Chironomidae family	Macroinvertebrate	Australia wide
Pea clam	*Sphaeridae* spp.	Macroinvertebrate	Australia wide
Ribbon worm	*Nemertea* spp.	Macroinvertebrate	Possibly introduced [5, 6]
Water mite	*Hydracarina* spp	Macroinvertebrate	Australia wide
Worm	Oligochaeta class	Macroinvertebrate	Australia wide

Notes:

[1] Previously *Edelia vittata.*

[2] Individuals found could be *C. albidus* or *C. destructor;* the appropriate species name for yabbies present in Western Australia is currently under review.

[3] For fish and crayfish refer to Morgan et al. (2011).

[4] DEC (2010).

[5] There is limited information available about the nativeness of macroinvertebrate species; in lieu of this the distribution of each species is listed (refer to MDFRC 2009).

[6] Gooderham & Tsyrlin (2003).

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