Ecological Responses to Environmental Water Provisions in the Onkaparinga River

David Schmarr and Dale McNeil

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Report to the SA Department for Water
The Adelaide and Mount Lofty Ranges Natural Resources Management Board
e-water Cooperative Research Centre

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Cover: Release of environmental water provision from Clarendon Weir in spring 2009.

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EXECUTIVE SUMMARY

Environmental water provisions (EWPs) have been planned for Onkaparinga River since 2006 but the delivery of planned environmental flows was delayed indefinitely due to drought. Increased rainfall in spring 2009 resulted in surplus water in Mount Bold Reservoir which had been filled to protect Adelaide's water supply demands. As a result, a large EWP was opportunistically released with the intent to improve ecological health of the Onkaparinga River. Boosted by heavy local rainfall in the lower Onkaparinga Catchment, the resultant flow into the previously parched lower Onkaparinga River peaked at >3000 ML/day.

Prior to this event, the Department of Water, Land and Biodiversity Conservation in partnership with the Adelaide and Mount Lofty Ranges Natural Resources Management Board, funded a three year study into the sustainability and flow requirements of native fish populations in the lower Onkaparinga River. Data collected in this study indicated that native fishes in the lower Onkaparinga River were suffering declines in distribution and abundance under the increasingly harsh drought conditions, characterized by limited river flows.

The current project was conducted to determine the response of the native fish community to the flow release and to assess the benefits that the flow had on the sustainability of fish populations, habitat, and water quality within the river reach. Monitoring of fish populations directly after the event revealed that the flow had provided only moderate initial environmental outcomes with the flushing of previously saline pools upstream of Old Noarlunga leading to the re-establishment of diadromous fish species (i.e. common galaxias and congolli) in habitats previously populated with marine fishes. Subsequently, declining water quality conditions due to seawater incursion resulted in the loss of fish from those pools.

Eight months after the EWP, fish populations exhibited no positive response to the flow allocation and continued to display declining distributions and abundances in line with the drought related decline of the previous years. Diadromous fishes also failed to recolonise the Gorge reach upstream to Clarendon, likely as a result of the short duration of the flow release in relation to the longer periods of hydrological connectivity required for such fish movements. In addition, the pools above Old Noarlunga had once again become saline suggesting that the short term flushing flows were not adequate to fully flush salts, or that tidal incursions were not countered with river flows to maintain freshwater habitats in the lower gorge section.

The responses of fish populations to the environmental allocation are discussed in relation to the specific ecological outcome targets set out under the EWP trial. Conclusions and recommendations are presented in this report addressing aspects of the EWP that may be

improved with the strategic addition of flow bands as set out in the EWP report. Additional modeling using tools developed by the eWater CRC will further inform the planning and delivery of flow bands by tailoring flows to the ecological needs of each fish species and the maintenance of appropriate water quality regimes. This will help to improve the allocation of water resources for maintaining ecological sustainability in the Onkaparinga River and other catchments under future environmental flow allocations.

1. INTRODUCTION

The catchments of the Western Mount Lofty Ranges (WMLR) drain westward across the Adelaide plains and into Gulf St. Vincent. The Onkaparinga River is the largest catchment in the Mount Lofty Ranges (MLR) and drains a large section of the central MLR, flowing through Adelaide's southern suburbs before entering the gulf at Port Noarlunga (Figure 1). Significant and continuing anthropogenic modification has occurred since European settlement in the mid nineteenth century (Twidale *et al.* 1976). Modifications have been both hydrological through capture and storage of water resources to support agricultural and urban community uses; and physical as a result of land use and urbanisation. The construction of water storage reservoirs, weirs and transfer infrastructure has greatly altered the natural flow regime and distribution of water within and across catchments and several regulatory structures represent significant barriers to fish movement. Subsequently, their role as aquatic ecosystems has been dramatically changed from pre-European condition (McNeil and Hammer 2007).

Streams within the MLR are impacted variously by river regulation; flow releases are typically highly managed and driven by water usage patterns and human demand, and many systems have been cut off from natural catchment flows which are captured and diverted to upstream water storages (Kawalec and Roberts 2005). As a result, the magnitude, frequency, duration and timing of river flows have changed from 'natural' patterns, all of which are critical components of riverine flow regime, and key mechanisms driving riverine ecosystems (Poff *et al. 1*997). These ecosystems and inhabitant aquatic biota are often highly dependent on particular aspects of natural flow regime (McNeil *et al.* 2009).

Flow regime determines the physical, chemical and biological nature of riverine habitats and provides connectivity between catchment components both longitudinally and laterally. Critically, many aquatic organisms have evolved life history strategies that rely directly on specific components of the natural flow regime and on patterns of longitudinal and lateral connectivity (Bunn and Arthington 2002; Lloyd *et al. 2*003). Native fish species in particular are dependent on a wide range of flow regime components having evolved to survive within the highly variable conditions within Australia's waterways (Puckridge *et al.* 2000, Lloyd *et al. 2*003, Lintermans 2007).

Throughout the freshwater systems, flows provide habitat for the survival of all freshwater fish species present in the WMLR. These fish species are unable to survive periods of desiccation (Bunn and Arthington 2002; McNeil, Gehrig *et al.* 2009), and require adequate flows to prevent declines in water quality that can reach lethal levels within isolated waterholes under

inadequate flow regimes (McNeil and Closs 2007). In the MLR, the increasing impacts of drought and high levels of river regulation led to the development of management plans to address the decreasing level of freshwater flows, particularly in river reaches that were considered to possess high ecological value (Pikusa and Bald 2005). In the Onkaparinga River, a significant effort was directed towards identifying the environmental water requirements of the catchment (SKM 2003) including consideration of local native fish (SKM 2002) with a view to developing Environmental Water Provisions (EWPs) for the delivery of environmental flows (Gatti *et al.* 2005).

A comprehensive study of the ecology of fish in the WMLR was conducted between 2006 and 2008 (McNeil *et al.* 2010). Initially one of the major objectives of that study was to monitor the effect of trialing EWPs on the ecology of fish in the Mount Lofty Ranges. Due to drought and a lack of water for the environment during that study, no EWPs were applied except for a small trial release in the Onkaparinga River in 2006. The effect of the lack of flow during that project was profound. The distribution and abundance of several native species was low or decreased over the project period, species adapted to low-flow environments thrived and introduced species dominated many reaches. However, the small trial flow in the Onkaparinga River in 2006 was successful in stimulating some movement and recruitment of species within the reach, although this may also have been linked to a large natural flow in November 2005 (McNeil *et al*. 2010).

With the exception of the aforementioned low-flow event, flows in the Onkaparinga Catchment from 2006-2009 have remained low. The river has dried annually into a series of isolated pools each summer with limited spring and autumn connectivity, and flowing each winter only after significant local rainfall. These conditions have resulted in deterioration of water quality and habitat quality within refuge habitats in the reach and a general decline in the ecological health of the native fish community (McNeil *et al.* 2009, SARDI unpublished data).

In late September 2009, large widespread rainfall events in the MLR caused Mount Bold Reservoir to fill and a short-lived flow peaking at >3000ML/day occurred over two days in the lower Onkaparinga River after flowing over Clarendon Weir. Subsequent rainfall in mid-October was released more slowly over approximately nine days, peaking at ~1600ML/day. These two flows were the first to be released from Mount Bold down the Onkaparinga River since a 5000ML flow in November 2005. The latter flow was described as an environmental flow in a press release from the Minister for the Environment and Conservation (SAMEC 2009). Given the scarcity of water for the environment over the past 4 years, it is important to determine that any water released from reservoirs that is described as an environmental flow fulfils ecological

objectives. Detailed objectives for environmental flows have been developed under the Western Mount Lofty Ranges Environmental Water Provisions project for the Western Mount Lofty Ranges including the Onkaparinga River (Pikusa and Bald 2005).

The objectives outlined in the EWP plan (Pikusa and Bald 2005) included:

- Provide longitudinal connection for fish migration;
- Maintain and improve water quality;
- Maintain self-sustaining fish populations;
- Maintain and restore habitat diversity for macroinvertebrates;
- Control terrestrial vegetation in the river channel;
- Reset aquatic habitat;
- Summer low flows – maintain shallow water habitat and improve water quality in pools;
- Summer freshes – flush pools to improve water quality and increase habitat value;
- Winter low flows – create surface water flow sufficient to fill low flow channels providing migration opportunities for fish and macroinvertebrates, not significantly impacting depth of pools;
- Winter freshes – provide longitudinal connection between pools and allow migration for fish and macroinvertebrates but not scouring biofilms or sediment;
- Large winter pulses – reset habitat and ecosystem processes by scouring sediments and biofilms, also aiding in vegetation control.

1.1. Objectives

The current project was designed to collect ecological information regarding the response of the fish populations to the October 2009 flows in the lower Onkaparinga River and to relate these responses to previous conditions within the reach and to the objectives outlined for environmental flow delivery. The specific aims of the project were:

1. Monitor the effect of the 2009 e-flow on the ecology of fish in the Onkaparinga River with respect to:
    a. Immediate ecological changes such as abundance, distribution and recruitment in comparison to previous long-term monitoring observations
    b. Medium-term changes in the months following the EWP

2. Determine whether the EWP met any of the specific objectives set out in previous planning documents and provide recommendations for future EWPs based on the findings of recent flow events.

2. METHODS

2.1. Site description

Located approximately 25 km to the south-east of Adelaide, the Onkaparinga River is the largest catchment area in the Mount Lofty Ranges, covering an area of 560 km². The Onkaparinga Catchment is the largest contributing catchment to Adelaide's water supply with additional water inputs coming from the Murray River via a pipeline entering the river near Hahndorf. The Onkaparinga Catchment provides water for domestic, agricultural, horticultural and industrial use with most of its surface water captured in farm dams, reservoirs and weirs (Kawalec and Roberts 2005). Large storages exist at the Mount Bold Reservoir and the Clarendon Weir with additional off takes from Clarendon piped to Happy Valley Reservoir. The construction of Mount Bold Reservoir has lead to a drastic reduction in surface flows within the lower Onkaparinga River downstream of Clarendon Weir with flows ceasing altogether during summer (Pikusa and Bald 2005). In this reach, channel flows are largely dependent upon local catchment rainfall runoff and input from a few small tributary streams, of which Kangarilla Creek is the only significant contributor except under extreme rainfall and flow conditions when Clarendon Weir becomes breached (Kawalec and Roberts 2005).

This section of the Onkaparinga River is dominated by the Onkaparinga Gorge, much of which lies within the Onkaparinga National Park but has been historically modified for grazing. Upstream from the National Park are number of large agricultural developments, in particular wineries that abstract water from pools in the main channel, and stock impacts are conspicuous throughout this reach. The riparian and gorge area is dominated by introduced weed species, although in sections, reasonable densities of native trees and shrubs remain, including river redgum (*Eucalyptus camaldulensis*), wattles (*Acacia* spp.), *Callistemon sieberi*, and *Leptospermum spp* (Nicol and Bald 2006). Below the Gorge section, the Onkaparinga River comes under estuarine influence and is brackish or marine between Old Noarlunga and the sea with the principal freshwater/estuarine interface proximal to the Church Track causeway within the park.

The sampling design was based upon the monitoring framework developed in conjunction with the project steering committee, presented in detail in McNeil and Hammer (2007) and used for previous monitoring work in the MLR (McNeil *et al.* 2010). The sampling design consisted of three sites within the EWP target reach; the first was within 1 km of each flow release point, the second was positioned approximately 5 km downstream of the upstream site to compare sites

that directly receive full e-flow releases with those farther downstream that may receive lesser flow volumes from the same releases. A third site at the very bottom of the catchment assessed the impact that e-flow releases may have on coastal and diadromous fish populations.

The three fish monitoring sites in the lower Onkaparinga River are located downstream of Clarendon Weir (Figure 1). Sampling sites were established at 'Clarendon Oval', directly downstream of the Weir; 'Brooks Road', situated within the central gorge several kilometres downstream of the weir, and 'Old Noarlunga' at the foot of the gorge where freshwater reaches graduate into brackish and estuarine reaches under tidal influence, a further several kilometres downstream from Brooks Rd (Figure 1Figure 2; Table 1). As such, this study covers the section between the Clarendon Weir and the Onkaparinga River estuary.

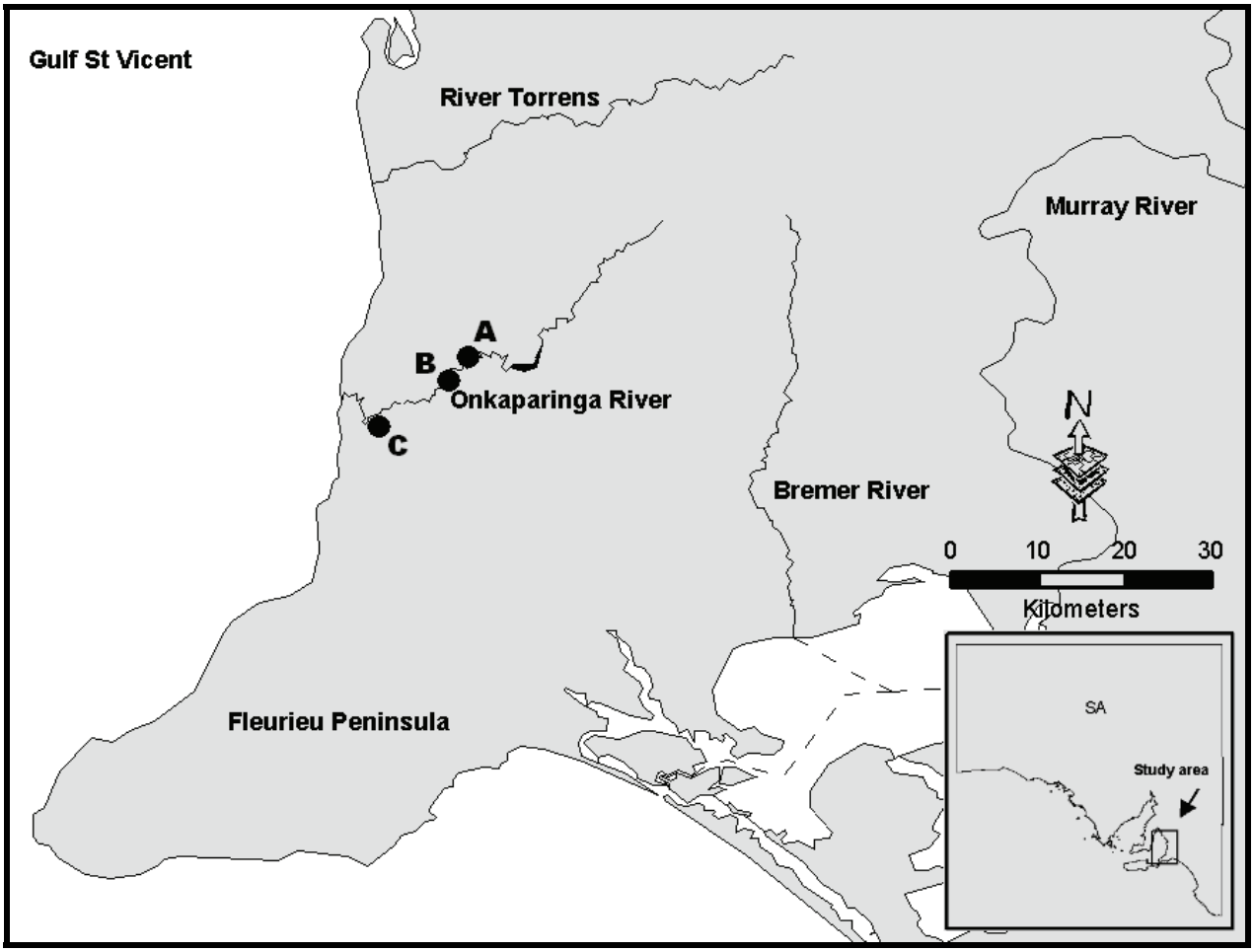

Figure 1. Map showing the location of the Onkaparinga River sampling sites in the Western Mount Lofty Ranges, South Australia. A) Clarendon Weir, B) Brooks Road, C) Old Noarlunga.

Table 1. GPS coordinates in Universal Transverse Mercator (UTM) for the pools surveyed within each of the Onkaparinga River sites.

Site	Pool	GPS coordinates (UTM)
Clarendon Oval	1	54 H 283928 - 6112029
	2	54 H 284042 - 6111876
	3	54 H 284098 - 6111835
Brooks Road	1	54 H 281823 - 6109101
	2	54 H 281823 - 6109101
	3	54 H 281823 - 6109101
Old Noarlunga	1	54 H 273248 - 6104526
	2	54 H 273248 - 6104526
	3	54 H 273248 - 6104526

Figure 2. Map showing the location of the three sampling sites on the Onkaparinga River. Each site consisted of three adjacent pools and interconnecting riffle/run reaches.

The Clarendon Oval Site (Figure 3) was situated at the Clarendon Oval reserve and consisted of three separate pools within a 300 m reach approximately 500 m downstream of the Clarendon Weir. The Brooks Rd Site was situated in the Onkaparinga Gorge several kilometres downstream of the Clarendon Weir. All pools were situated within a 300 m reach of the river

(Figure 4). The Old Noarlunga Site encompasses the lower freshwater reaches of the river immediately above the normal upper influence of the tidal estuary (Figure 5). All pools are situated at the base of the Onkaparinga Gorge and encompassed by the National Park.

Figure 3. Location of the three monitoring pools at the Clarendon Oval Site on the Onkaparinga River.

Figure 4. Location of the three monitoring pools at the Brooks Road Site on the Onkaparinga River.

Figure 5. Location of the three monitoring pools at the Old Noarlunga Site on the Onkaparinga River.

2.2. Field sampling

The post e-flow fish survey was carried out in spring 2009 (26-29 October) at all the three sites. A second survey was conducted in early winter 2010 to gauge the medium-term benefits of the e-flow for fish movement and recruitment. The early winter survey was conducted between 16 and 18 June, but due to time constraints did not include all pools surveyed in spring. Instead, based on our experience of sampling these sites over the past three years, representative pools were selected from within the three sites - Pool 2 at Clarendon, Pool 2 at Brooks Rd and Pools 2 and 3 at Old Noarlunga.

At each pool sampled, four small fyke nets (Figure 7a) (3 m leader, 2 m funnel, 3 mm mesh) and two large fyke nets (5 m leader, 4 m funnel, 6 mm mesh) were set (Figure 6). In addition, two double winged fyke nets (Figure 7b) (5 m wings, 3 m funnel, 3 mm mesh) were placed at either end of each pool to capture any fish moving through or into the reach (Figure 6). All fykes were set with a buoyed cod-end to enable surface access for air-breathing by-catch and weighted at each end and point with chain, or attached to stakes. This set of nets was sufficient to saturate smaller pools whilst in some larger pools nets were set to cover all major habitat types (Figure 8).

The principal focus of the sampling strategy was: a) to provide as comprehensive as possible data on species presence, and b) to gain an idea of the relative abundance of fish species across sites and for comparison to previous sampling seasons. Nets were set for ~24 hours at each site with the three pools set in a single day and retrieved the following day.

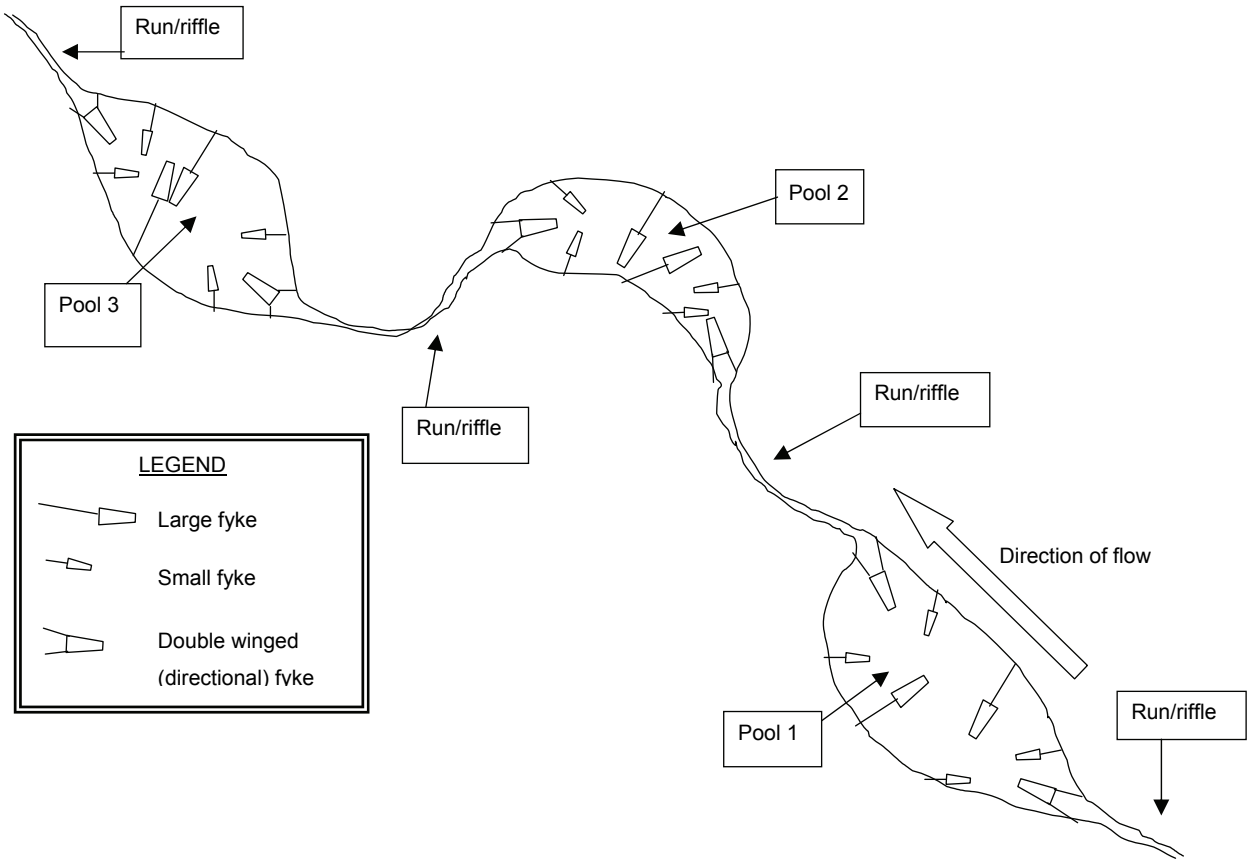

Figure 6. Site sampling design consisting of three netted pools. Reproduced from McNeil and Hammer (2007).

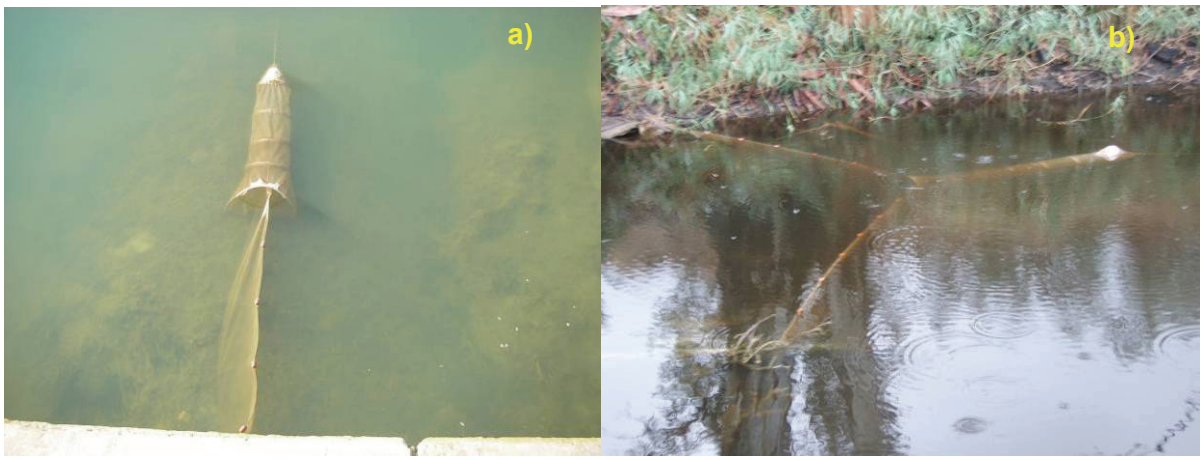

Figure 7. Fyke nets used for field sampling, a) small fyke net and b) double winged fyke net.

Figure 8. A typical set of fyke nets in a pool at Brooks Rd Site in the Onkaparinga River.

All fish were then identified, counted and measured for total length. Breeding condition and the presence of disease or parasites were also recorded. Where very large numbers of fish were collected, length measurements were only taken from a sub-sample of the total fish catch. Sub-sampling was conducted by ensuring that at least the first fifty fish of each species were measured; however in all cases, all fish within the selected net were measured, even if more than fifty were present. This ensured that sub-sampling errors did not result in very large or small individuals within a catch being neglected during measurement. Breeding condition was assessed by ‘squeezing’ the underbelly of each fish and recording the presence of eggs or

sperm issuing from the vent. For new records or uncertain identifications, some voucher species were retained.

2.3. Habitat and physico-chemical characteristics of sites

A number of physical, chemical and flow parameters were assessed each sampling season including: percent cover and composition of riparian vegetation, size structure of streambed substrates, absolute maximum depth, the number of snags within each pool, percent cover and composition of aquatic macrophytes, and maximum depth during sampling. Water quality measures including dissolved oxygen, pH, salinity and water temperature were measured using a YSI 6920 sonde. Current flow condition was recorded by observation and antecedent flow regime was obtained from the Department of Water, Land and Biodiversity Conservation (DFW) surface water archive website.

The composition of aquatic macrophytes and riparian vegetation was determined using Sainty and Jacobs (1994) cross checked with previous vegetation records where possible from Nicol and Bald (2006). Visual estimates of cover were made in relation to pool surface area. Assessment of emergent macrophytes were found to vary between estimators and a protocol was developed whereby emergent stems were counted in macrophyte cover estimates, ignoring stems that may be present upon banks and not available as physical fish habitat at the time of sampling. As a result, some estimates of macrophyte cover vary greatly between seasons due to pool depth as stranded beds of *Typha* and *Phragmites* became inundated at higher water levels.

Maximum depth was recorded at the same point each season at the deepest point in each pool. Water temperature, pH, dissolved oxygen and conductivity were assessed during each sampling trip with a TPS water quality multi-meter. Water quality was measured 150 mm below the water surface in a central part of each pool and where depth was sufficient, additional samples were taken for each parameter at 500 mm depth intervals until the probes touched the substrate. For consistent comparison, only the surface water quality values are presented in site summary tables.

Flow condition was categorized for each pool and each sampling season as either ‘No flow’, ‘Low flow’, or ‘High flow’ via visual assessment made at the downstream extent of survey pools. Antecedent flow conditions relate to the six month period preceding each sampling trip to capture the recent flow conditions prior to sampling for each season. These conditions were classified based on the EWP flow classes determined for each target river (Pikusa and Bald 2006) as ‘No flow’, ‘Very low flows’, ‘Low flows’, ‘Freshes’ and ‘Flushes’. Additional categories were added to account for low and very low flow conditions that occurred over the sampling

period. These low flow categories differentiated between small and/or infrequent periods of flow and extended periods of baseflow as set out in the EWP proposal (Pikusa and Bald 2006). Categorization was made using hydrographs provided by Water Data Services (WDS) recorded from DFW and Adelaide and Mount Lofty Ranges NRM Board (AMLRNRMB) hydrometric stations.

3. RESULTS

3.1. General Results: Onkaparinga River

Fourteen species of fish were recorded during the survey, with five species recorded previously from the reach not observed (Table 2). Five introduced species were also caught in the survey. Flat-headed and dwarf flat-headed gudgeons were the most widely distributed fish, present at all sites during both seasons. *Gambusia* were also present at all sites with the exception of the spring survey at Old Noarlunga. Mountain and climbing galaxias, redfin, goldfish, tench and carp were restricted to the upper section of the gorge, whilst common galaxias, congolli, gobies, hardyhead and black bream were restricted to the lower reaches of the river (Table 2). A more detailed presentation of habitat, water quality and fish data are presented for each site separately in the following sections.

Table 2. Relative abundance (CPUE in fish per net) for each site and season (Spring = S and Winter = W). The columns of native freshwater fish taxa are shaded green, those of exotic taxa shaded red and those of marine/estuarine taxa shaded blue. Species captured in past surveys but not captured in the present survey are included.

		Common galaxias	Mountain galaxias	Climbing galaxias	Flat-headed gudgeon	Dwarf flat-headed gudgeon	Shortfin eel	Eastern gambusia	redfin	Goldfish	Carp	Tench	Congolli	Bridled Goby	Swan River Goby	Tamar Goby	Smallmouth hardyhead	Black bream	Jumping mullet	Yellow-eyed mullet
Clarendon Oval	2009 S		0.21	0.25	8.00	0.08		0.96	0.58		0.04	0.04								
	2010 W				5.88	0.63		0.50	0.13											
Brooks Road	2009 S		0.29	0.08	20.88	1.54		0.71		0.08										
	2010 W				15.63	0.88		24.25												
Old Noarlunga	2009 S	12.00			6.54	0.21							0.88			0.04				
	2010 W	15.13			5.38	0.13		0.31					8.31				0.06	1.63		

3.1.1. Clarendon Oval Site

3.1.1.1. Site assessment

The pools at Clarendon Oval Site were similar in size and depth with Pool 2 being the smallest and shallowest (Table 3). The substrate in all pools was dominated by cobbles over 10 mm diameter with large littoral sections of emergent macrophytes, predominantly *Typha domingensis* and *Phragmites australis.* The riparian zone was largely dominated by exotic deciduous trees with a few redgums whilst blackberry and fig trees dominated the understory. Pool 3 had a denser riparian overstorey than the others. All pools were bordered by a rocky cliff on the right bank (facing downstream) with modified parkland on the left bank. A long section of overgrown shallow riffle habitat separated Pool 1 and Pool 2, whilst Pool 2 and Pool 3 were separated by a short section of *Phragmites*. Pools were connected after releases of water from Mount Bold Dam but became isolated over summer and autumn.

Table 3. Habitat characteristics of the three monitoring pools at Clarendon Oval Site in the Onkaparinga River.

Clarendon Oval	Substrate size (mm)	Riparian cover	Snags	Absolute max. depth
Pool 1	10+	30%	0	2.0m
Pool 2	10+	21%	1	1.8m
Pool 3	10+	95%	3-4	2.2m

Pool 1 was situated on a bend with high cliff on the right bank. Large rocks and cobbles dominated the substrate. The left bank was dominated by *Typha* with a riparian overstorey of wattle and redgum with some callistemon (*Callistemon Sieberi*). The right bank consisted primarily of fig (*Ficus spp.)* and blackberry, with no overstorey. This pool was at bank level during spring 2009 sampling (Table 4). Water quality parameters were consistent with the other pools in this site. Submerged macrophyte cover was low with water ribbon *Triglochin procerum* present although rare. In spring 2009, and again in winter 2010, this pool was flowing slightly.

Table 4. Water quality parameters recorded in Pool 1 of Clarendon Oval Site during spring 2009.

Pool 1	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (ºC)	Max. depth (m)	Macrophyte (% cover)	Hydrology	Antecedent Hydrology
2009	spring	7.19	747	7.25	17.25	2	15	Low flow	Flushes
2010	winter	Not	surveyed					Low flow	No flow

Pool 2 (Figure 9a) was almost completely surrounded by emergent *Phragmites* with small patches of *Typha.* The right bank was rocky cliff whilst neither bank possessed significant

riparian overstorey except for a single callistemon, a small silver willow (*Salix* spp.*)* and some blackberry. This pool remained at bank level during spring 2009 sampling and again in winter 2010 (Table 5). Dissolved oxygen was similar in this pool between spring 2009 and winter 2010, temperature varied greatly between spring and winter. Salinity in both spring 2009 and winter 2010 was low. Low flow conditions existed during both spring 2009 and winter 2010.

Figure 9. Clarendon Oval Site a) Pool 2 in winter 2010 and b) top of Pool 3 in spring 2009.

Table 5. Water quality parameters recorded in Pool 2 of Clarendon Oval Site during spring 2009 and winter 2010.

Pool 2	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (ºC)	Max. depth (m)	Macrophyte (% cover)	Hydrology	Antecedent Hydrology
2009	spring	6.15	745	7.85	16.76	1.8	20	Low flow	Flushes
2010	winter	5.67	1313	7.65	7.00	1.8	10	Low flow	No flow

Pool 3 (Figure 9b) was the farthest downstream with the right bank dominated by a cliff with two callistemons overhanging the pool. The upstream end of pool 3 was surrounded with *Typha* and *Phragmites*, however the left bank was dominated by tall exotic trees and a few redgums with little ground cover or understorey. The downstream end of the pool opened into a wide riffle/run section and connected to a larger corner pool downstream when full. A deep section below a rock ledge on the right bank made this the deepest of the three Clarendon pools. Water quality parameters were consistent with the other pools at this site (Table 6).

Table 6. Water quality parameters recorded in Pool 3 of Clarendon Oval Site during spring 2009.

Pool 3	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (ºC)	Max. depth (m)	Macrophyte (% cover)	Hydrology	Antecedent Hydrology
2009	spring	7.87	706	7.81	17.94	2.2	20	Low flow	Flushes
2010	winter	Not	surveyed					Low flow	No flow

3.1.1.2. Hydrology

Data from the Clarendon Oval gauge indicated that over the last three years there had been periods of several months over summer/autumn when there was insufficient surface water to maintain any flow, followed by intermittent periods of winter flow and occasional small flushes (Figure 10). In late September 2009, large widespread rainfall events caused Mount Bold Reservoir to fill and a large short-lived flushing flow peaking at over 3000ML went down the Onkaparinga River over two days. Subsequent rainfall in mid-October was released more slowly over approximately nine days, peaking at 1600ML. These two flows were the first large flushes to flow down the Onkaparinga River since a 5000ML flow in November 2005 (Clarendon Oval gauge wasn't operational until May 2006). After the flow in October 2009, low flows continued until they ceased in mid-December.

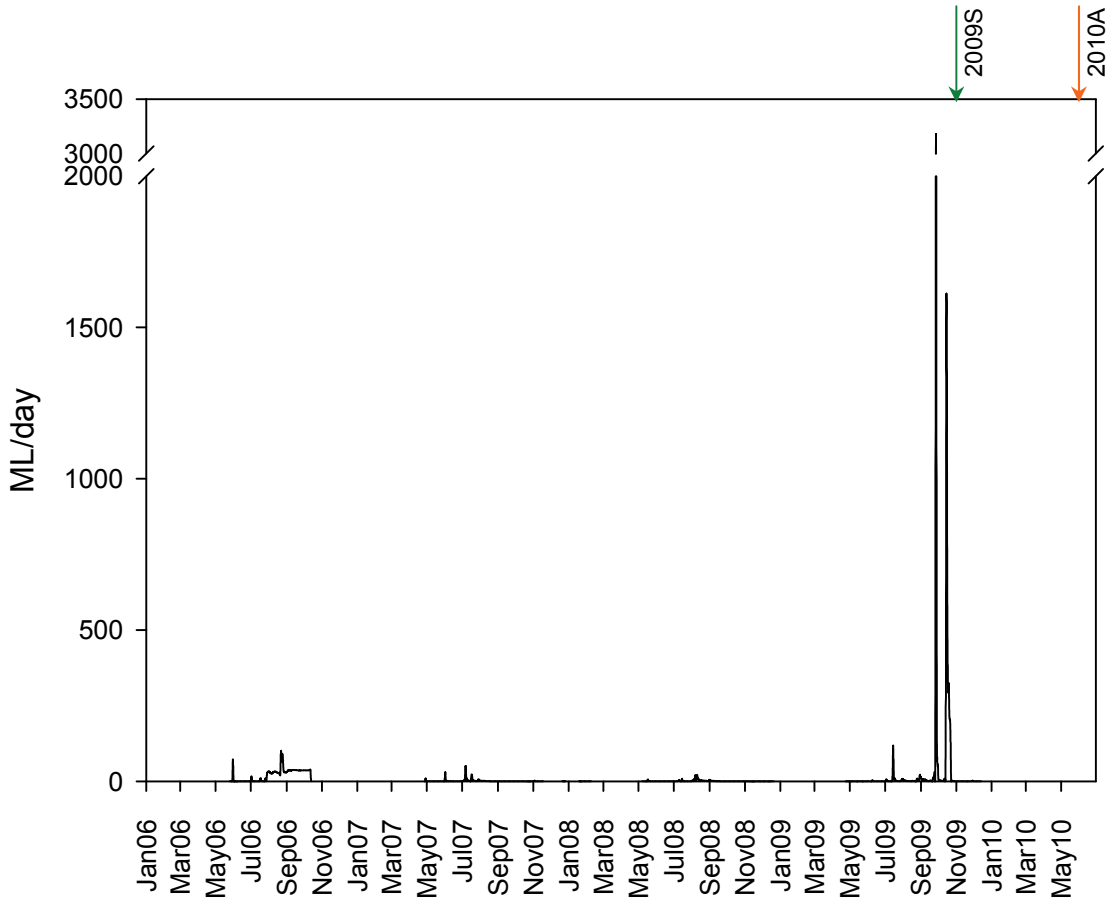

Figure 10. Hydrograph for flow in Onkaparinga River at Clarendon Oval Site. Flow data (ML/day) was collected downstream of Clarendon Oval (WDS gauge number A5031004) from 21 May 21 2006. The timing of each survey is shown above the figure.

3.1.1.3. Fish community

Four native species (flat-headed gudgeon, dwarf flat-headed gudgeon, climbing galaxias and mountain galaxias) and four introduced fish species (gambusia, redfin, carp and tench) were captured at Clarendon Oval Site during spring 2009 (Table 2). In winter 2010 just two native species captured (flat-headed gudgeon and dwarf flat-headed gudgeon) and two introduced species (gambusia and redfin).

3.1.1.4. Fish populations

Flat-headed gudgeon were abundant in spring 2009, but had decreased in abundance by winter 2010 (Table 2) although there was a small cohort of new recruits (Figure 11). Dwarf flat-headed gudgeon increased in abundance between surveys (Table 2) and the relatively large number of smaller fish indicates recruitment success (Figure 12). Only one juvenile climbing galaxias was captured at Clarendon Oval in spring 2009 (Figure 13). Larger numbers of mountain galaxias were captured in spring, but they too had disappeared by winter 2010 (Figure 14). Gambusia became less abundant between spring and winter (Table 2, Figure 15). Redfin perch also declined between spring and winter (Table 2), with none of the large number of juveniles captured in spring recaptured in winter (Figure 15). Only one large carp (Figure 17) and one large tench (Figure 18) were captured during the spring survey, but not in the following winter survey.

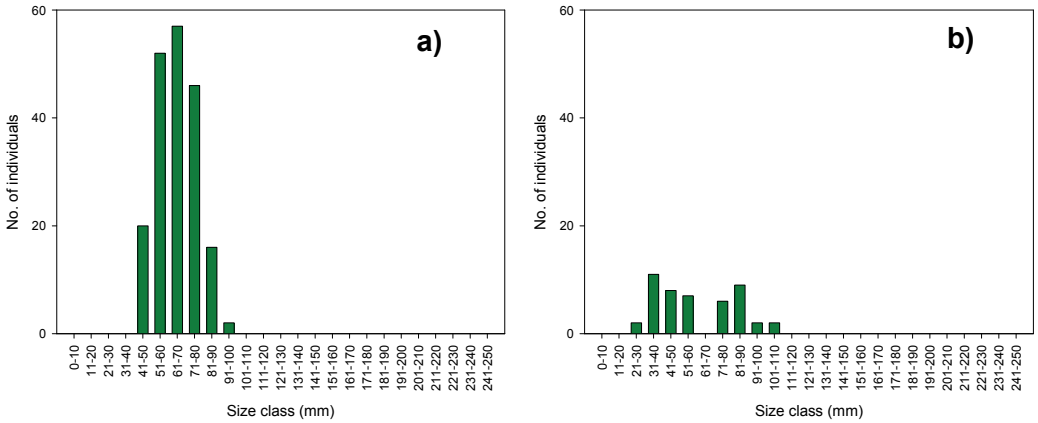

Figure 11. Lengths of flat-headed gudgeon (*Philypnodon grandiceps*) at Clarendon Oval Site of Onkaparinga River in a) spring 2009 and b) winter 2010.

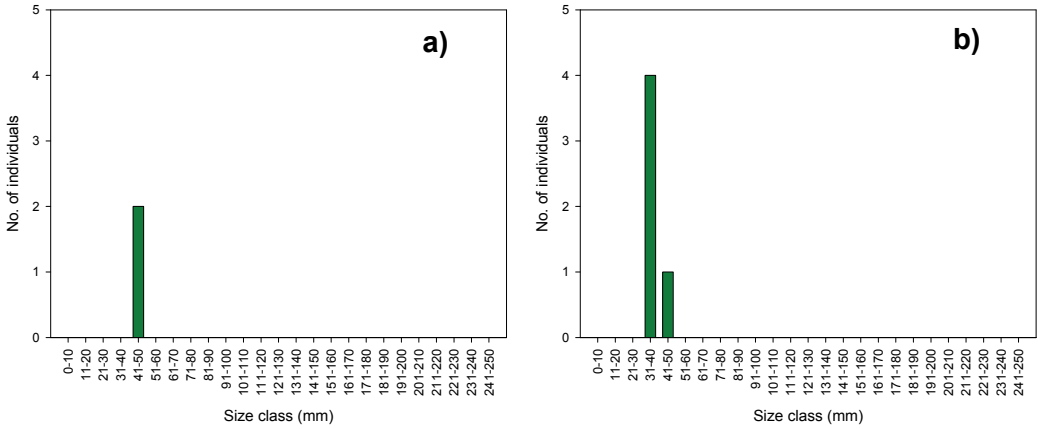

Figure 12. Lengths of dwarf flat-headed gudgeon (*Philypnodon macrostomus*) at Clarendon Oval Site of Onkaparinga River in a) spring 2009 and b) winter 2010.

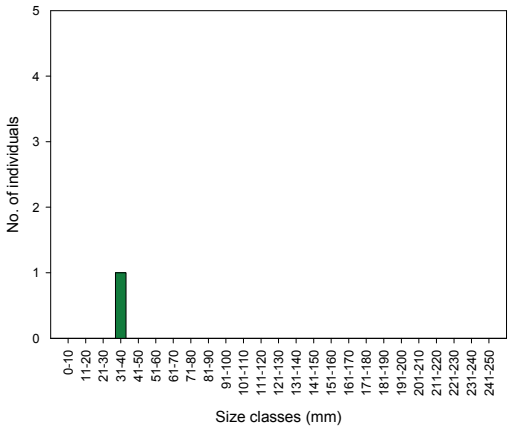

Figure 13. Lengths of climbing galaxias (*Galaxias brevipinnis*) at Clarendon Oval Site of Onkaparinga River in spring 2009.

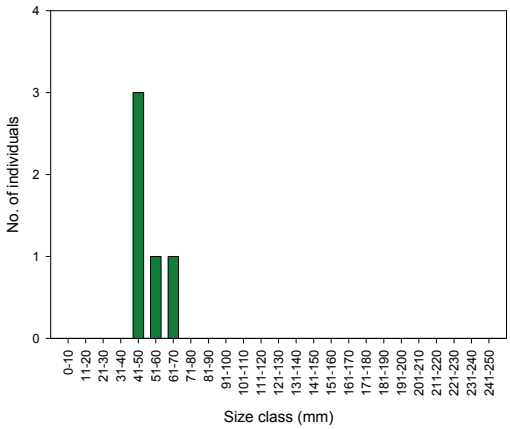

Figure 14. Lengths of mountain galaxias (*Galaxias olidus*) at Clarendon Oval Site of Onkaparinga River in spring 2009.

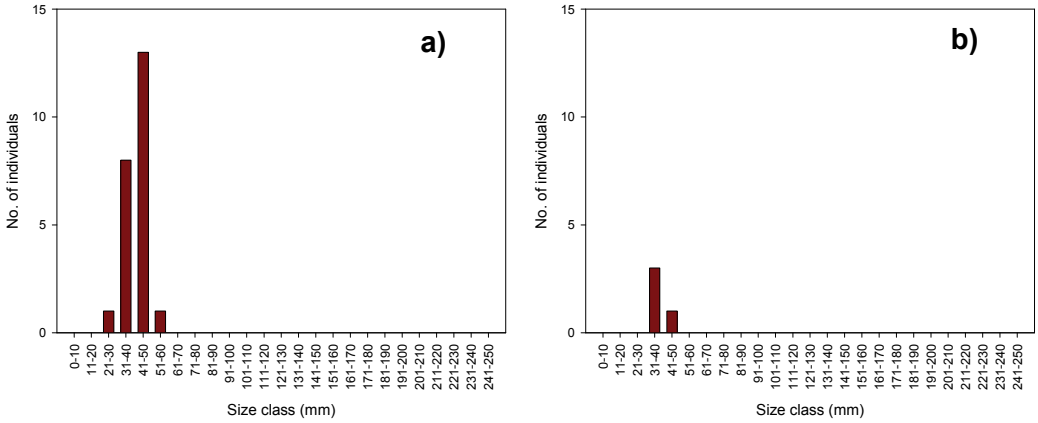

Figure 15. Lengths of gambusia (*Gambusia holbrooki*) at Clarendon Oval Site of Onkaparinga River in a) spring 2009 and b) winter 2010.

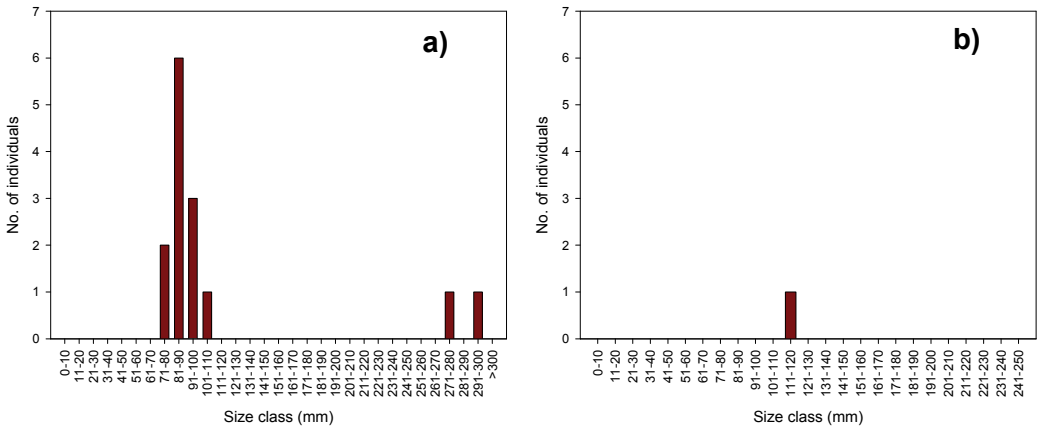

Figure 16. Lengths of redfin perch (*Perca fluviatilis*) at Clarendon Oval Site of Onkaparinga River in a) spring 2009 and b) winter 2010.

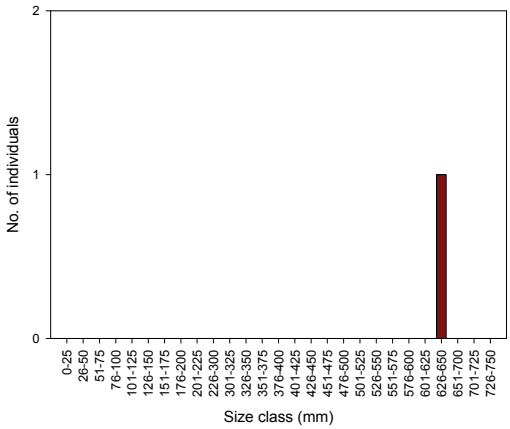

Figure 17. Lengths of carp (*Cyprinus carpio*) at Clarendon Oval Site of Onkaparinga River in spring 2009.

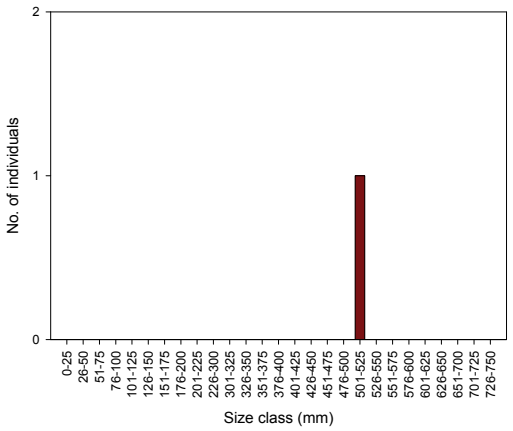

Figure 18. Lengths of tench (*Tinca tinca*) at Clarendon Oval Site of Onkaparinga River in spring 2009.

3.1.2. Brooks Road Site

3.1.2.1. Site assessment

Pool 1 and pool 2 were connected when full in spring, at opposite ends of a deep section of bedrock based river, with Pool 1 being somewhat shallower than Pools 2 and 3 (Table 7), whilst Pool 3 was separated from that section by ~ 30-40 m of riffle. The reach was dominated by solid bedrock with some large rocks present and steep gully on either bank. Riparian vegetation was not laterally extensive but consisted of large redgums and relatively high numbers of callistemon, leptospermum and wattle. The site was very rocky and dominated by the introduced foxtail grass *Pennisetum villosum* (Nicol and Bald 2006), which formed a very dense understorey over 1 m tall extending to the water's edge. This section was wholly within the Onkaparinga Gorge National Park although historical clearing was apparent and revegetation of the gorge has been recently undertaken (Figure 4).

Table 7. Habitat characteristics of the three monitoring pools at Brooks Road Site in the Onkaparinga River.

Brooks Road	Substrate size (mm)	Riparian cover	Snags	Absolute max. depth
Pool 1	10+-Bedrock	80%	0	1.2m
Pool 2	Bedrock	50%	1	2.5m
Pool 3	Bedrock	50%	0	2.0m

Pools 1 and 2 are at opposite ends of a large reach and are connected when full, but separate during the dry season. Pool 1 was relatively shallow and possessed a higher degree of cobbled substrate in relation to bedrock compared to the other two pools. Based on previous studies, this

pool is one of the most ephemeral selected for the current study. In spring 2009, this pool was full from the recent flows; salinity and oxygen saturation were in a healthy range (Table 8). The pool was surrounded on three sides with emergent *Typha* and *Phragmites* with a patchy overstorey of redgum, callistemon, some wattles. Riparian vegetation was overwhelmingly dominated by Texas needlegrass (*Nassella leucotricha)*. Submerged macrophytes were rare but present.

Table 8. Water quality parameters recorded in Pool 1 of Brooks Road Site during spring 2009.

Pool 1	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (ºC)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2009	spring	9.49	687	8.17	17.04	1.2	5	No flow	Flushes
2010	winter	Not	surveyed					No flow	No flow

Pool 2 (Figure 19) was deeper and more permanent than Pool 1 and possessed a principally bedrock substrate, with little macrophyte cover (Table 9). Pool 2 had a largely bedrock substrate and was relatively deep. Oxygen and salinity concentrations were above levels considered to impact on fish (McNeil & Closs 2007). Macrophytes, largely ribbonweed, were rare but present in spring 2009 and in winter 2010. Riparian vegetation consisted of a few large overhanging redgums and smaller callistemons. Areas of *Phragmites* were present, largely along the right bank, whilst Texas needlegrass covered rocky riparian areas around the rest of the pool. This pool was isolated and not flowing in either the spring or winter sampling periods.

Figure 19. Pool 2 of Brooks Road Site in a) spring 2009 and b) winter 2010.

Table 9. Water quality parameters recorded in Pool 2 of Brooks Road Site during spring 2009 and winter 2010.

Pool 2	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (ºC)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2009	spring	9.2	700	8.11	17.12	2.5	5	No flow	Flushes
2010	winter	11.26	1347	8.17	8.5	1.4	0	No flow	No flow

Pool 3 was downstream of pool 2 separated by a well shaded riffle section. Whilst a single pool when full, this pool dried into two separate pools both of which were sampled in spring. In spring 2009, this pool was full from the recent flows; salinity and oxygen saturation were in a healthy range.

Table 10. Water quality parameters recorded in Brooks Road Pool 3 during spring 2009.

Pool 3	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (ºC)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2009	spring	12.32	711	8.46	18.06	2	5	No flow	Flushes
2010	winter	Not	surveyed					No flow	No flow

3.1.2.2. Hydrology

The Brooks Road Site is downstream from the Clarendon Oval Site and has a similar hydrology. The detailed description of the hydrology at Clarendon Oval during the current surveys is provided above. The only point of difference was that small local flows that had refilled the Clarendon Oval Site had not reached the Brooks Road Site by the time of the winter 2010 survey.

3.1.2.3. Fish community

Four native species (flat-headed gudgeon, dwarf flat-headed gudgeon, climbing galaxias and mountain galaxias) and two introduced fish species (gambusia, goldfish) were captured at Brooks Road during spring 2009 (Table 2). By winter 2010 there were only two native species captured (flat-headed gudgeon and dwarf flat-headed gudgeon) and one introduced species (gambusia).

3.1.2.4. Fish populations

As with Clarendon, flat-headed gudgeon were abundant in spring 2009, but had decreased in numbers by winter 2010 (Table 2) although again there was a small cohort of new recruits (Figure 20). Dwarf flat-headed gudgeon decreased in abundance (Table 2) and showed minimal

recruitment (Figure 21).

Small numbers of new climbing galaxias (Figure 22) and mountain galaxias recruits (Figure 23) were present in the spring survey, but were not captured again in winter. The gambusia population was very small after the flows in spring (Table 2), but had recruited well over summer (Figure 24). Two large goldfish were captured during the spring survey (Figure 25), but not in the following winter survey.

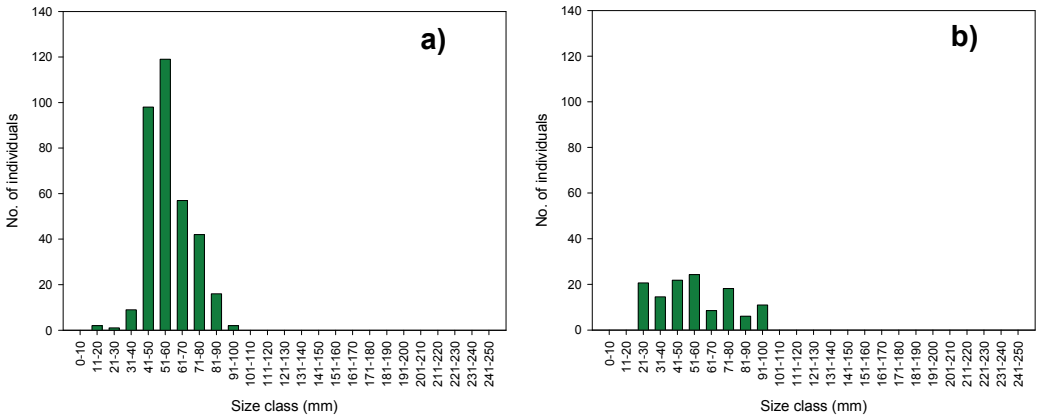

Figure 20. Lengths of flat-headed gudgeon (*Philypnodon grandiceps*) at Brooks Road Site of Onkaparinga River in a) spring 2009 and b) winter 2010.

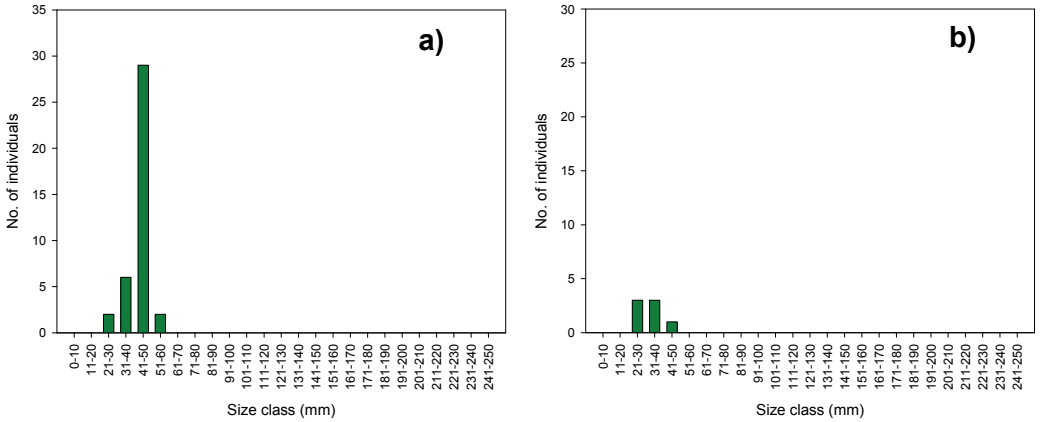

Figure 21. Lengths of dwarf flat-headed gudgeon (*Philypnodon macrostomus*) at Brooks Road Site of Onkaparinga River in a) spring 2009 and b) winter 2010.

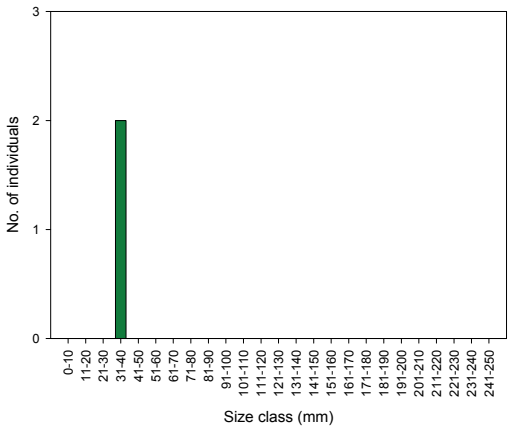

Figure 22. Lengths of climbing galaxias (*Galaxias brevipinnis*) at Brooks Road Site of Onkaparinga River in spring 2009.

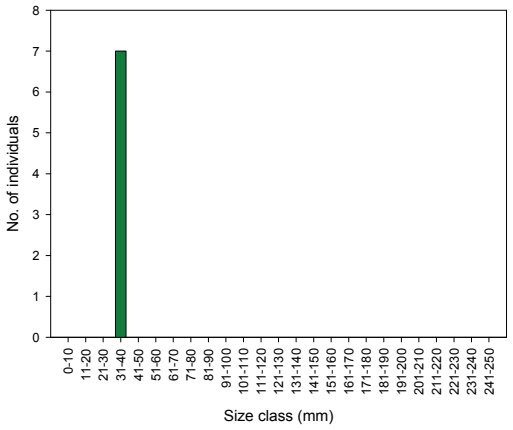

Figure 23. Lengths of mountain galaxias (*Galaxias olidus*) at Brooks Road Site of Onkaparinga River in spring 2009.

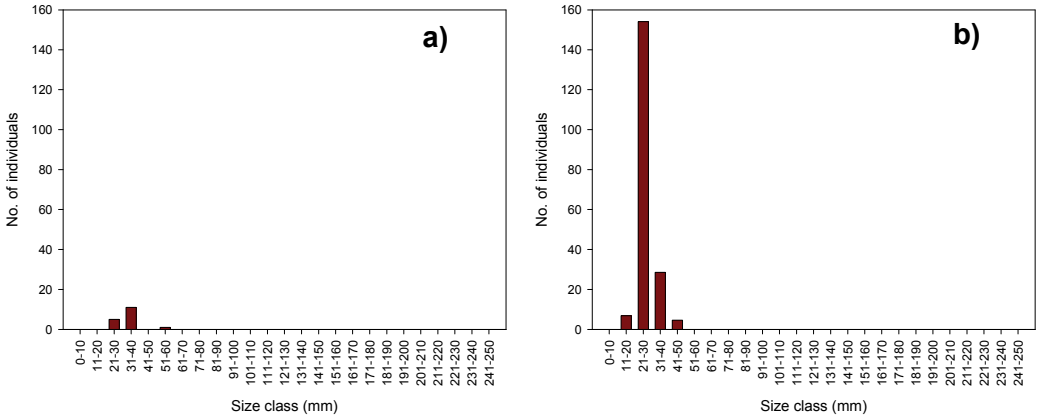

Figure 24. Lengths of gambusia (*Gambusia holbrooki*) at Brooks Road Site of Onkaparinga River in a) spring 2009 and b) winter 2010.

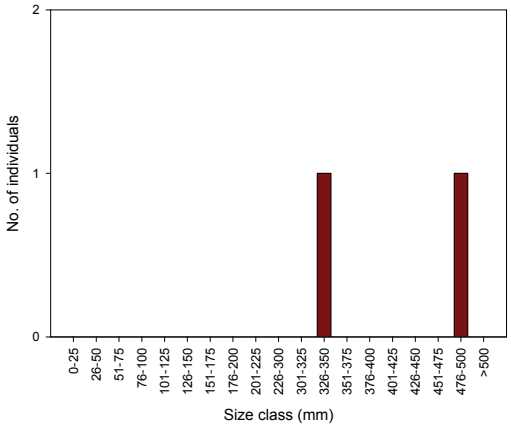

Figure 25. Lengths of goldfish (*Carassius auratus*) at Brooks Road Site of Onkaparinga River in spring 2009.

3.1.3. Old Noarlunga Site

3.1.3.1. Site assessment

The three pools at Old Noarlunga Site were relatively deep, particularly Pools 2 and 3, with rocky substrate and bedrock sections (Table 11). These pools had a higher density of woody debris (snags) than other sites and riparian vegetation at all pools was dominated by native species primarily redgum and callistemon. All three pools were surrounded with dense emergent vegetation primarily *Phragmites* and *Typha*.

Table 11. Habitat characteristics of the three monitoring pools at Old Noarlunga Site in the Onkaparinga River.

Old Noarlunga	Substrate size (mm)	Riparian cover	Snags	Absolute max. depth
Pool 1	10+	45%	7	2.5m
Pool 2	5-10+	15%	25	3.5m
Pool 3	5-10+	25%	20+	3.5m

Pool 1 was the shallowest at the Old Noarlunga Site (Table 12), located at the hydrometric weir where an SA Water pipeline undermines the stream. The upstream pool had moderate flow and full to bank level conditions during spring 2009 sampling. Salinity was low with good DO concentrations. Macrophytes were abundant at Pool 1 with large areas of emergent *Phragmites* and submerged beds of water ribbon and *Potamogeton crispus*, covering approximately 60% of the pool. The pool was overhung with large redgums and some callistemon and was reasonably well-shaded (Figure 113). Riparian vegetation comprised much Texas needlegrass (*Nassella leucotricha)*. Sampling in spring was preceded by the two large September and October flushing flows.

Table 12. Water quality parameters recorded in Pool 1 at Old Noarlunga Site during spring 2009

Pool 1	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (ºC)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2009	spring	6.79	871	7.63	17.09	2.5	10	Low flow	Flushes
2010	winter	Not	surveyed					No flow	No flow

Pool 2 is a deep permanent freshwater pool predominantly bedrock-based with cobbled substrate towards the downstream end. The pool consists of a long deep channel approximately 2 m in depth and 50 m long which opens into a deep pool 3.5 m in depth and surrounded by emergent macrophytes (Figure 26). This large pool is dominated by a large redgum snag (whole tree) whilst other snags are abundant throughout the pool length. Riparian vegetation is fairly dense with large redgums and callistemons along both banks. Macrophytes mainly consisted of *Phragmites* which surrounded the pool and extended into the pool especially within the shallower downstream section. Whilst dissolved oxygen and other water quality parameters remained relatively stable throughout the sampling period, salinity in winter 2010 was elevated significantly (Table 13). Pool depth remained very consistent at this site fluctuating only 0.2 m between surveys. Low flow was detected during the sampling in spring 2009 but no flow in winter 2010.

Figure 26. Pool 2 at Old Noarlunga Site in a) spring 2009 and b) winter 2010.

Table 13. Water quality parameters recorded in Pool 2 at Old Noarlunga Site during spring 2009 and winter 2010

Pool 2	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (ºC)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2009	spring	6.62	916	7.61	16.94	3.5	20	Low flow	Flushes
2010	winter	6.88	8440	7.71	10.3	3.0	20	No flow	No flow

Pool 3 (Figure 27) is a large and deep pool surrounded by *Phragmites* with sparse redgum and callistemon in the riparian zone. This was the most environmentally variable pool within the study with significant swings in salinity. Whilst the pool was fresh during spring 2009 sampling, salt water intrusion due to very large tidal and storm swells led to marine conditions in the pool in winter 2010 (Table 14). There appeared to be a small amount of freshwater flow during the winter 2010 sampling which freshened surface waters slightly (46500 µS/cm) However, because of the low volume of flow and strong stratification preventing mixing, subsurface waters remained marine. More detailed salinity mapping, not presented here, revealed that salinity was strongly stratified in this pool in winter 2010. Dissolved oxygen readings at depth (1.5-2.0 m) were also measured but are not presented in tables as they were not recorded for all sites. These data however, showed moderately low concentrations (2.2 ppm) at depth in spring 2009, but in winter 2010, DO levels were hypoxic below 1 m depth, declining to levels not sufficient for fish respiration (McNeil and Closs 2007).

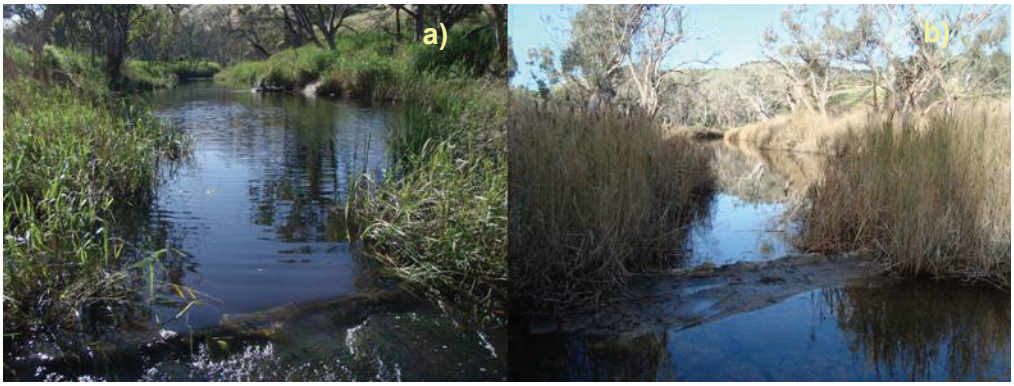

Figure 27. Pool 3 at Old Noarlunga Site in a) spring 2009 and b) winter 2010.

Table 14. Water quality parameters recorded in Pool 3 at Old Noarlunga Site during spring 2009 and winter 2010.

Pool 3	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (ºC)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2009	spring	6.48	1011	7.5	16.04	3.5	10	Low flow	Flushes
2010	winter	0.68	52200	7.13	16.3	3.5	10	No flow	No flow

3.1.3.2. Hydrology

Data from the Old Noarlunga gauge shows a similar pattern to the Clarendon Oval gauge in that over the last three years there have been periods of several months over summer/autumn when there is insufficient surface water to maintain any flow, followed by intermittent periods of winter flow and occasional small flushes (Figure 28). The large flushing flows that were recorded at Clarendon Oval were recorded at Old Noarlunga with peaks of nearly 10000ML/day and

4000ML/day. These two large flows were the first large flushes to flow down the Onkaparinga River since a 5000ML/day flow in November 2005 (Clarendon Oval gauge wasn't operational until May 2006). After the flow in October, low flows continued until they ceased in mid-December. No flow was recorded up to the time of the winter 2010 survey, although there was a trickle of flow going over the ford at Pool 3 due to tidal water moving into and out of the pool (Figure 27).

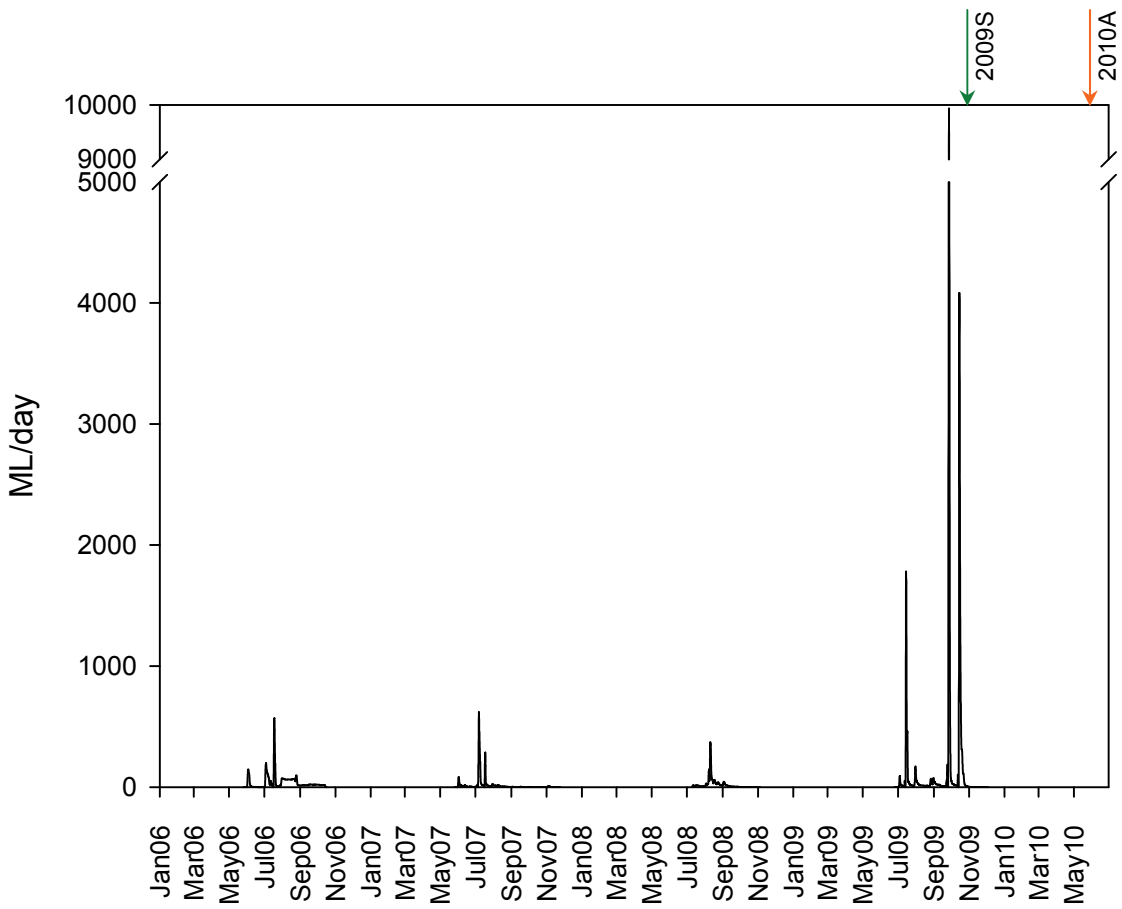

Figure 28. Hydrograph for flow in Onkaparinga River at Old Noarlunga Site. Flow data (ML/day) was collected upstream of Old Noarlunga (WDS gauge number A5031005). The timing of each survey is shown above the figure.

3.1.3.3. Fish community

Five native species (flat-headed gudgeon, dwarf flat-headed gudgeon, common galaxias, congolli and Tamar goby) were captured at Old Noarlunga Site during spring 2009 (Table 2). By winter 2010 there were an additional two native species captured (black bream and smallmouth hardyhead), and the introduced species gambusia. Tamar gobies were not captured in winter 2010.

3.1.3.4. Fish populations

Flat-headed gudgeon numbers declined in abundance between spring and winter surveys (Table 2), but there was some recruitment and the proportion of flat-headed gudgeon in the estuarine pool (pool 3) increased significantly (Figure 29). Dwarf flat-headed gudgeon abundance was low for both surveys and none were captured in the estuarine pool in winter (Figure 30). Common galaxias increased in abundance (Table 2) showing strong recruitment over the summer months with a large number of juveniles captured in winter, but they had all moved out of the estuarine pool into Pool 2 or elsewhere in winter (Figure 31). Congolli also showed strong recruitment over summer and the bimodal distribution of size classes may indicate sex segregation (i.e. females in freshwater and males in salt water) that is common for congolli (Figure 32). One Tamar goby was captured in spring, but not in winter (Figure 33). In winter 2010, black bream (Figure 34) and a single smallmouthed hardyhead (Figure 35) were captured in the estuarine part of the Old Noarlunga Site reflecting the transition of this pool from freshwater in spring to estuarine in winter.

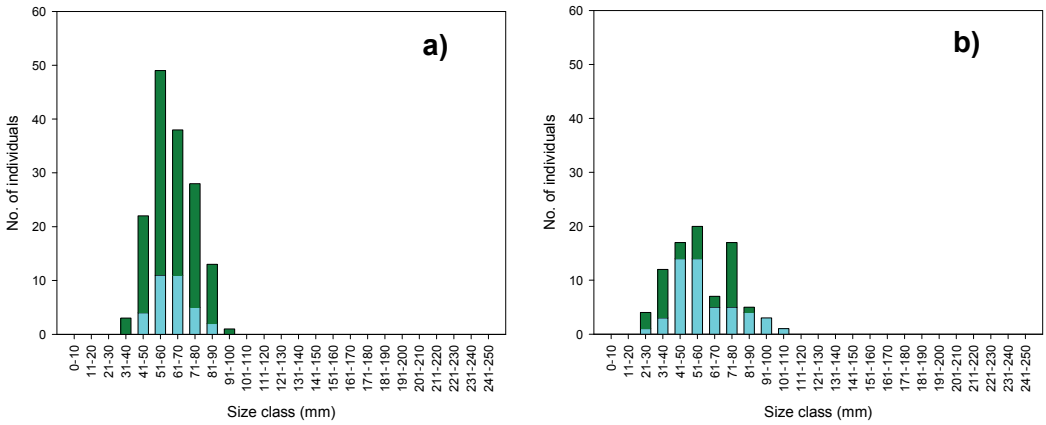

Figure 29. Lengths of flat-headed gudgeon (*Philypnodon grandiceps*) at Old Noarlunga Site of Onkaparinga River in a) spring 2009 and b) winter 2010. Dark green bars indicate fish captured in fresh water, light blue bars indicate fish captured in estuarine waters.

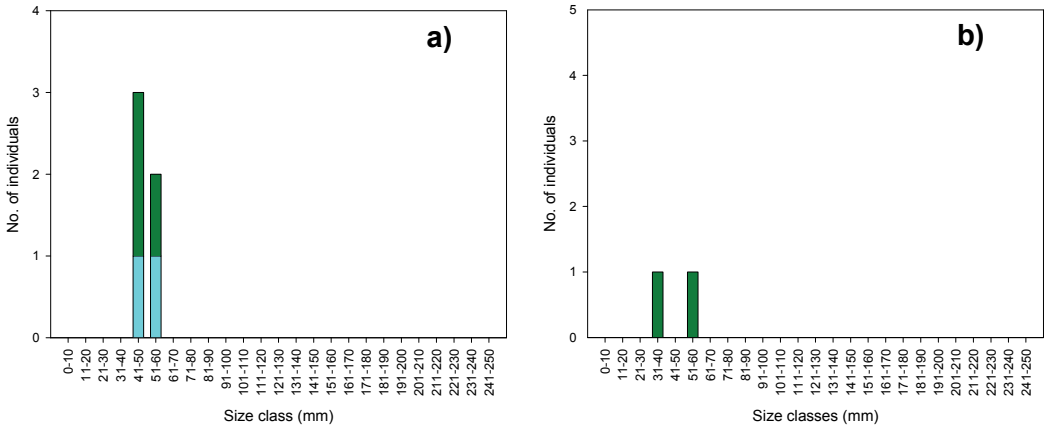

Figure 30. Lengths of dwarf flat-headed gudgeon (*Philypnodon macrostomus*) at Old Noarlunga Site of Onkaparinga River in a) spring 2009 and b) winter 2010. Dark green bars indicate fish captured in fresh water, light blue bars indicate fish captured in estuarine waters.

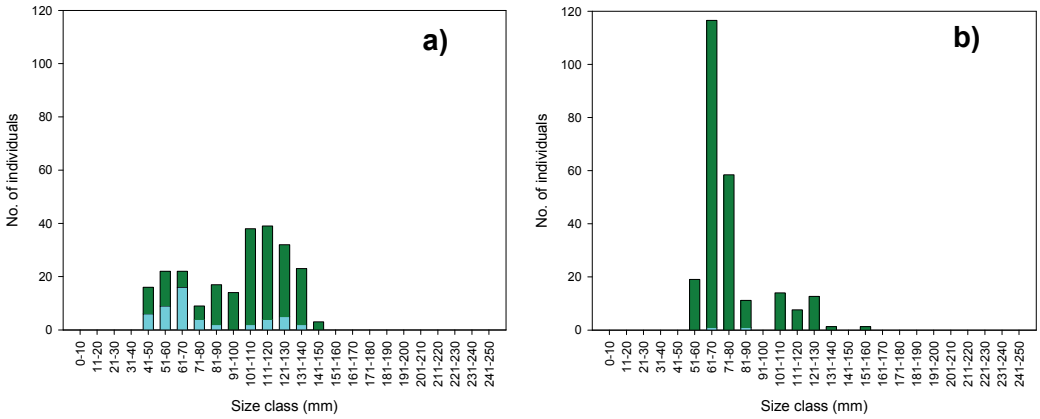

Figure 31. Lengths of common galaxias (*Galaxias maculatus*) at Old Noarlunga Site of Onkaparinga River in a) spring 2009 and b) winter 2010. Dark green bars indicate fish captured in fresh water, light blue bars indicate fish captured in estuarine waters.

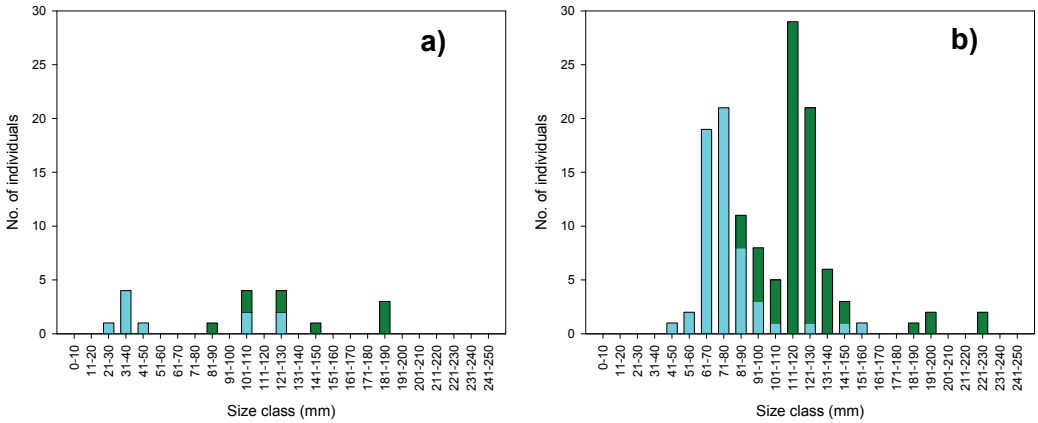

Figure 32. Lengths of congolli (*Pseudaphritis urvillii*) at Old Noarlunga Site of Onkaparinga River in a) spring 2009 and b) winter 2010. Dark green bars indicate fish captured in fresh water, light blue bars indicate fish captured in estuarine waters.

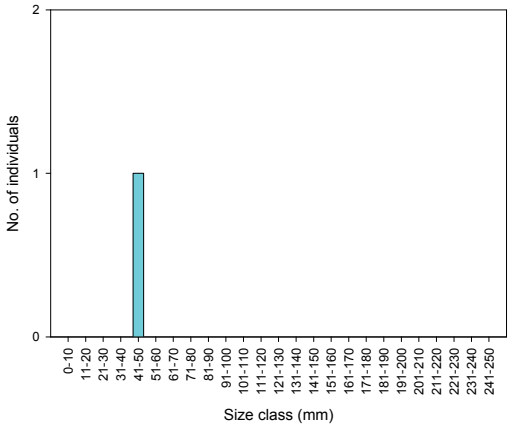

Figure 33. Lengths of Tamar goby (*Afurcagobius tamarensis*) at Old Noarlunga Site of Onkaparinga River in spring 2009. Dark green bars indicate fish captured in fresh water, light blue bars indicate fish captured in estuarine waters.

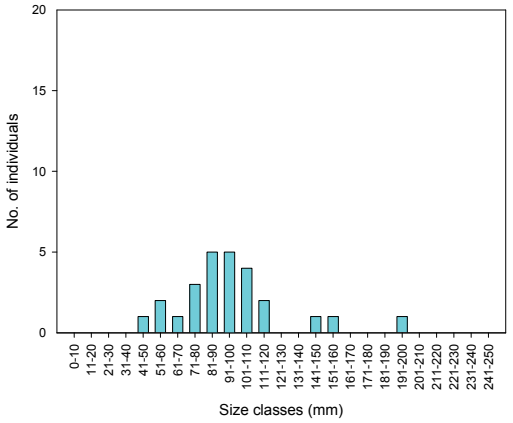

Figure 34. Lengths of black bream (*Acanthopagrus butcheri*) at Old Noarlunga Site of Onkaparinga River in winter 2010. Dark green bars indicate fish captured in fresh water, light blue bars indicate fish captured in estuarine waters.

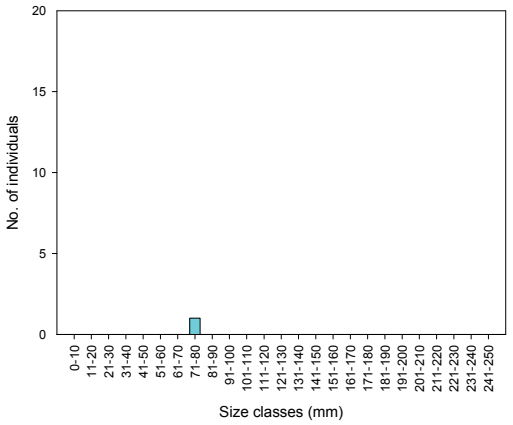

Figure 35. Lengths of smallmouth hardyhead (*Atherinosoma microstoma*) at Old Noarlunga Site of Onkaparinga River in winter 2010. Dark green bars indicate fish captured in fresh water, light blue bars indicate fish captured in estuarine waters.

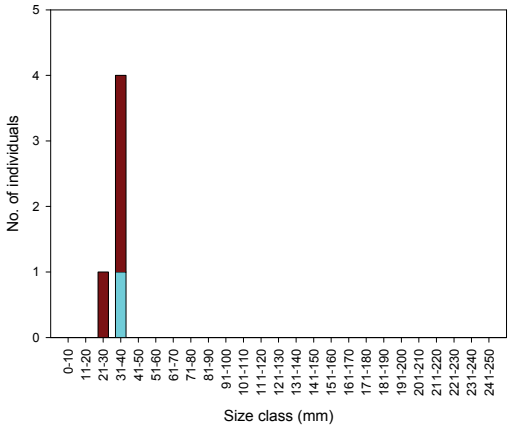

Figure 36. Lengths of gambusia (*Gambusia holbrooki*) at Old Noarlunga Site of Onkaparinga River in winter 2010. Dark green bars indicate fish captured in fresh water, light blue bars indicate fish captured in estuarine waters.

4. DISCUSSION

4.1. Species response

The survey revealed that the common species known to inhabit the reach (McNeil *et al.* 2010) are still present; however the distribution of many species within the reach is greatly diminished and decreased between the spring and early winter survey of the current study. Low numbers of mountain galaxias and climbing galaxias occurred at two sites in spring 2009 but not in winter 2010, either because they were absent or had significantly declined in abundance to a point where they were undetectable. This supports the general pattern of decline in distribution of galaxiid species identified within the lower Onkaparinga River by McNeil *et al.* (2010). Conversely, the distribution of generalist freshwater species, such as flat-headed and dwarf flat-headed gudgeon, appears to be stable throughout the reach. It is likely that these trends reflect the loss of flow that leads to decreased habitat availability benefitting generalist benthic species, whilst distribution of flow-dependent pelagic species decreases as a result of a loss of migration and spawning cues and heterogeneous flow habitats.

This pattern is also reflected in the abundance of species at each site, with flat-headed gudgeon highly abundant as well as ubiquitous in distribution. Other native freshwater species however, were found in extremely low numbers compared to past surveys suggesting that the population size and diversity of freshwater dependant species continued the pattern of decline observed during the worsening drought from 2002 - 2009 (SKM 2002, McNeil *et al.* 2010). It is clear from these patterns that the October 2009 environmental flows have not resulted in an increase in the distribution or abundance of freshwater species in the lower Onkaparinga River, and that drought conditions and the observed impacts on the fish community continued despite the allocation.

Introduced pest species remain distributed throughout the catchment, with Gambusia a dominant part of the fish fauna across all sites. The species is known to prefer stable water levels and respond poorly to the seasonal fluctuations inherent in natural Australian flow regimes (Tonkin and MacDonald 2009, Perna *et al.* 2009) and thus recent low flow conditions in the lower Onkaparinga River have likely favoured this species. The widespread distribution of other introduced pests, redfin, carp, goldfish and tench in the upper part of the reach in low abundances has remained unchanged.

Only two estuarine species were captured in the spring survey compared to the seven recorded during past surveys. Over recent years, sea-water intrusions into formerly freshwater habitats upstream of Old Noarlunga Site has resulted in a shift in fish fauna from one dominated by freshwater species to one dominated by estuarine species. Nevertheless, it appears that the large volume of flow released in October 2009 was sufficient to freshen these habitats enough to enable the re-establishment of freshwater and diadromous fish populations in this area. However, the 2010 survey revealed that, whilst these populations remain, salinity in the lower Onkaparinga River has again risen to seawater levels and that their long term viability remains threatened unless significant flushing and freshening flows can be delivered in the near future. These surveys did not include assessments in the estuarine reaches of the Onkaparinga River and as a result conclusions cannot be drawn about the response of estuarine fish species in those habitats, although this warrants further investigation as the estuarine fish community is also likely impacted by lack of freshwater inputs.

The diadromous species, common galaxias and congolli, exhibited recent recruitment and were sampled in moderate numbers around the Old Noarlunga Site. Recent flow conditions appear to have facilitated spawning and migration, whilst enabling the recruitment of juvenile fish into freshwater reaches. Common galaxias, however, did not recolonise the middle and upper sections of the reach. Whilst healthy populations of common galaxias were present right up to the Clarendon Oval Site following trial environmental flows in 2006, they declined steadily in the absence of environmental flow allocations with populations contracting to and remaining within the lowest habitats around the Old Noarlunga Site. This pattern is significant in relation to the October 2009 environmental flow as this did not meet the specific requirements for migration of diadromous species between the sea and Clarendon (as described in Mackay *et al.* 2008).

A key aspect of this flow requirement relates to the duration of low flows and freshes being sufficient to provide connectivity and allow migration of young fish over several weeks during their migratory season. Although the seasonality of the October 2009 flow was appropriate, it appears that the duration of connectivity required for migration was not met. As such, the status of common galaxias in the Onkaparinga River also remains unchanged from recent drought patterns. Congolli are not known to migrate far upstream and therefore the recent recruitment suggests that flow management over the past year has been adequate for population sustainability. The reductions in salinity levels in their preferred refuge habitats near the Old Noarlunga Site will benefit this species, but recently rising salinities may reduce the benefits provided by recent environmental flows.

The lack of flow over summer and autumn has another effect on fish distribution apart from restricting movement. Without sufficient flow, riffles between pools and the complex habitat at the edge of pools (i.e. amongst emergent macrophytes, snags and cobble) dries out, resulting in a loss of habitat diversity. Riffles and complex habitat are essential for galaxiid species for reproduction, feeding, movement and as cover from predators (McDowall and Fulton 1996). As these habitats dry out, galaxiid and other species lose cover and are more likely to come into contact with gambusia and other predators such as redfin.

4.2. Ecological objectives

To determine whether the October 2009 environmental flows were successful in achieving desired environmental benefits, observed responses and patterns in the fish data can be applied to the stated ecological objectives for the Onkaparinga River as determined by the Mount Lofty Ranges Environmental Water Provisions project (Pikusa and Bald 2005). The following section addresses each of the ecological objectives set out for EWPs under that project in relation to the data collected under the current project. Where appropriate, recommendations for improving the delivery of environmental flows are also provided.

1. Provide longitudinal connection for fish migration;

The duration of the EWP was most likely too short to provide passage for fish to the middle and upper sections of the reach, and diadromous species remain restricted to the downstream extent of the river. Also, considering the very high velocity of the release, passage upstream was likely impeded for most species. It is recommended that future environmental flows be enhanced by delivery in conjunction with periods of freshes and low flows so that the flow peak can provide adequate conditions for capitalising on migratory response cues.

2. Maintain and improve water quality;

Water quality as measured during these surveys was satisfactory for supporting native fish populations. The EWP would have improved water quality directly after the release, although this was likely short-lived and had little effect on the maintenance of water quality over summer when salinity, temperature and oxygen conditions decline. The results show that whilst short term flushing improved conditions in the lowered reaches where salinisation had occurred, the flows were insufficient for maintaining freshness as salts leached out of sediments (and potentially suffered further salt water incursions) over the following months. The effect of these large flushes reducing nutrient levels in the river cannot be discounted but measurements were not made as part of this study.

3. Maintain self-sustaining fish populations;

Populations of many fish species do not appear to be sustainable under the current flow regime. Distributions and abundances of Climbing and Mountain *Galaxias* remained low throughout the reach. Congolli and common galaxias are maintaining sustainable populations in the lower reaches of the river and it is likely that these sites are important refuges for these species. The major concern is for specialist freshwater dependant species such as *Galaxias olidus* which continued to decline.

4. Maintain and restore habitat diversity for macroinvertebrates;

This aspect of the ecological outcomes was not monitored during this survey.

5. Control terrestrial vegetation of the river channel;

Anecdotal observations during the surveys noted that the EWP did contribute to controlling terrestrial vegetation in the river channel. Significant amounts of vegetation were dislodged and deposited in the riparian zone. This study did not adequately assess the response of vegetation communities.

6. Reset aquatic habitat;

Although not quantitatively measured by the surveys, the EWP may have reset aquatic habitats, removing built up sediment, nutrients and organic matter. However, without continued low flows and freshes, these habitats were not maintained to the benefit of fish species. For example, riffle habitats were cleared by the flushes providing ideal habitat for galaxiid species, but the flow through the riffles was not maintained for the fish to inhabit these areas or to maintain ecological process.

7. Summer low flows – maintain shallow water habitat and improve water quality in pools;

This EWP did not provide summer low flows. Shallow water habitats such as riffles and runs between pools are the preferred habitat of galaxiid species and these were not maintained, potentially contributing to further decline of galaxiid populations in the Onkaparinga River.

8. Summer freshes – flush pools to improve water quality and increase habitat value;

Summer freshes were not provided. Elevated salinity levels in all pools and high salinity levels at the Old Noarlunga Site in winter indicate that significant inflows had not occurred between the EWP and the survey in winter 2010.

9. Winter low flows – create surface water flow sufficient to fill low flow channels providing migration opportunities for fish and macroinvertebrates, not significantly impacting depth of pools;

Prior to the EWP in October 2009, there were low flows (>10ML/day) in the Onkaparinga River emanating from Kangarilla Creek. Above that point the Brooks Road and Clarendon Oval Sites rarely recorded flows of that magnitude. This goes some way to explaining the continued access of diadromous fish into the pools at Old Noarlunga Site, and the absence of fish migrating up into and between Brooks Road and Clarendon Oval Sites as the upper half of the reach remained disconnected for extended periods in winter leading up to the flow release. Winter flow release outlined under the EWP plan would increase the effectiveness of spring high flows by adding connectivity linkages between winter and spring flow events.

10. Winter freshes – provide longitudinal connection between pools and allow migration for fish and macroinvertebrates but not scouring biofilms or sediment;

Winter freshes were prevalent through the Old Noarlunga Site prior to the EWP but only one fresh greater than 20ML flowed through Clarendon Oval and Brooks Road Sites prior to the EWP (Figure 10). The freshes at Old Noarlunga Site were largely due to unregulated flows from Kangarilla Creek (DFW surface water archive) and other small tributaries after rainfall events. Rainfall in the upper catchment was captured by the reservoir and only one large rainfall event – 80mm from July 11-15 at Clarendon Oval Site – resulted in a fresh. The freshes prior to the EWP were naturally occurring but would have been more prevalent in the upper reaches of the river in the absence of the reservoir.

11. Large winter pulses – reset habitat and ecosystem processes by scouring sediments and biofilms, also aiding in vegetation control.

Two very large flushes were opportunistically delivered prior to the survey period, however these were not delivered in accordance with the planned EWP outlines. The flushes occurred within three weeks rather than over the two months as advised in planning. The flushes may have achieved some of their ecological objectives, such as vegetation control and restoring habitat, but in the absence of sustained low flows between flushes and over summer, the benefits may not have been as significant.

4.3. Future EWPs

Most of the ecological objectives listed above were not sufficiently addressed by the opportunistic release of environmental water in October 2009. The results of this study

suggest that the flow did not provide significant benefits to the overall ecological health of the Onkaparinga River. Although an exception was the short term relief of salinity impacts near Old Noarlunga Site, which supported good recruitment for diadromous fish to the local area. The ecological response for most species was poor in the longer term and the impacts of drought on the fish community of the Onkaparinga River have not been alleviated following the flow release.

In a press release from Minister for the Environment and Conservation, the Honorable Jay Weatherill, dated July 13th 2009, it was stated that due to the drought, EWP trials were halted in October 2006, but that

"… given the return of average flow conditions, these trials will be recommenced and valuable data on aquatic health can now be collected to help determine long term environmental flow releases that should be adopted. Downstream sections of the waterways will be monitored to assess ecosystem responses to these flows." (SAMEC 2009 pg 2).

In the press release it was implied that the single release of water from Mount Bold Reservoir as an EWP in October 2009 would *solely* improve ecological health in the river. However, the EWP trials were originally intended to be provided year-round as a strategically timed combination of flow conditions including low flows for all but three and a half months, numerous freshes of varying magnitude and three flushes of at least 650ML (Pikusa and Bald 2005).

Provided that average rainfall and flow conditions continue, future EWPs should be delivered according to the strategy outlined for the EWP trials in 2006 rather than opportunistically as has occurred over the last 12 months, with limited benefit to the receiving environment. As stated in the minister's press release, the river should be monitored to assess ecosystem responses to the flow. It must also be noted that if flow reverts to conditions endured over the previous four years of drought, then it is even more critical that some form of EWP becomes available to the ecosystem as natural limitations to local inflows greatly amplify the impact of not releasing water downstream of Clarendon Weir (McNeil *et al.* 2010). In summary, the isolated flow release in October 2009 provided little benefit to the ecological integrity of the Onkaparinga River, largely due to the isolated release of a single flow type.

The key recommendation of this study is that additional flow components such as freshes and low-flow provisions be added to any future releases to maximise the environmental benefit stemming from the allocation of precious water resources away from human use. The delivery of environmental flows must be dictated by knowledge of the response and dependence of aquatic biota to river flows. As such, EWPs should be of sufficient magnitude and duration and occur at the right time of year to facilitate flow-related processes integral to maintaining sustainable

fish populations. To determine the appropriate magnitude, duration and timing of flows, modelling tools recently developed by the eWater CRC should be applied to the ecological information gathered through this project. These tools account for the specific biological needs of each species to tailor flows in a way that limited environmental water can be most efficiently used to deliver the greatest possible ecological outcomes. Strategic planning and linking of flow bands will allow much greater and sustained water quality and ecological benefits to the reach.

The Onkaparinga Catchment maintains a base level of ecological uniqueness that warrants protection by natural resource managers, despite extreme impacts from recent drought and lack of flow provisions. Further development of our knowledge of ecological responses to flow provides us with the tools to enable that protection and begin to reinstate the catchment as a vibrant and healthy ecosystem.

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