Department of
Water

Collie River

Ecological Values Assessment

Wetland Research & Management

April 2009

Collie River

Ecological Values Assessment 2008

Prepared on behalf of:

Department of Water

Water Allocation Planning
The Atrium, Level 6, 168 St Georges Terrace, Perth WA
PO Box K822, Perth WA 6842

Ph (61 8) 6364 7600, Fax (61 8) 6364 7601

by:

Wetland Research & Management

28 William Street, Glen Forrest, WA 6071, Australia

Ph (61 8) 9298 9807, Fax (61 8) 9380 1029, e-mail: awstorey@cyllene.uwa.edu.au

Final Report

April 2009

Frontispiece: Collie River site 1B-1, below Burekup weir (centre);
Exotic *Nymphaea* sp. at Harris River site 1A-5, below Norm Road (bottom).

Study Team

Management: Andrew Storey
Fieldwork: Jess Lynas, Sue Creagh & Jess Sommer
Macroinvertebrate sorting and identification: Adam Harman & Jess Lynas
Report: Sue Creagh & Andrew Storey

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INTRODUCTION

The Department of Water (DoW) is undertaking water resource planning in the southwest of the State, including the Upper and Lower Collie surface water areas. This work will contribute to the development and review of management plans for both the Upper Collie statutory plan and the Lower Collie plan. The Upper Collie surface and groundwater area consists of all sub-catchments upstream of Wellington Dam, including the Collie River South and East branches and the Bingham and Harris rivers. The Lower Collie consists of all sub-catchments downstream of Wellington Dam to the confluence with the Brunswick River (Figure 1)

A draft plan for water resources in the Upper Collie surface and groundwater areas was released for public comment in December 2007 (DoW 2007c). The ultimate goal is to manage water resources of the Collie River for consumptive use and economic development while providing for ecological, social and cultural values consistent with the DoW's Environmental Water Provisions (EWP) Policy for Western Australia, Statewide Policy No. 5. Within this policy, the determination of ecological water requirements (EWRs) is an essential step. To do this the ecological values (existing, historical or proposed for restoration) must first be assessed as flows are provided to protect and/or enhance specific attributes and processes. Values may be derived from the review of prior recent studies or from specific field surveys. In some instances, a decision may be made to restore or enhance degraded values, using historical accounts of past values and/or processes. Ultimately, accurate recording of values is important (WRM 2007).

Once the key ecological values have been described, the DoW can determine the water regime criteria to sustain these values at a low level of risk. Allocation of water to meet EWRs is based on the premise that the environment has a right to water, that is, the environment has to be regarded as a legitimate user. Water dependant environmental values and non-consumptive social values are maintained through the setting of an EWP and an allocation limit that guides licence decisions. In general terms, a water requirement is determined through scientific investigation and community consultation and can be ascribed to a defined value. A water provision is the amount of water allocated from a resource to meet (wholly or in part) the requirement.

Study Reaches

Within the sub-catchments of the Collie River, some ecological values are well documented while others are not. DoW requested that the current study focus on selected values within four reaches (nodes):

i). Reach 1a Harris River below the Harris Dam (Upper Collie);
ii). Reach 1b Collie River below Burekup weir (Lower Collie);
iii). Reach 2 Collie River west of South Western Highway (Lower Collie);
iv). Reach 3 Henty Brook west of South Western Highway (Lower Collie).

The general location of the reaches is shown in Figure 1.

Harris River

The Harris River is a freshwater tributary of the Collie River East Branch, upstream from Wellington Reservoir and ca. 10 km north of Collie township (Figure 1). The Harris River is regulated by the Harris Dam, the reservoir of which has a catchment area of 382 km^2 and storage capacity of ca. 71 GL. Current estimates of sustainable yield are ~17 GL/yr (DoW 2007a). The catchment both above and below the Dam is predominantly State forest. Water from Harris Reservoir is pumped to Stirling Reservoir in the Harvey River catchment to the north. The water is used to supplement the water supply to the Perth Integrated Water Supply System (IWSS), which includes Perth, Mandurah, Harvey, Waroona and the Goldfields. However in recent years, pumping has been suspended due to low water levels in the Reservoir (DoW 2007b). In order that transfers to Stirling Reservoir can re-commence, the Water Corporation plan to construct a new treatment plant at Harris Dam to maintain water quality during periods of low water level (DoW 2007b). There are also plans to pump and temporarily store fresh dewatering discharge from the Collie Coal Basin in Harris Reservoir. This would then be transferred to Stirling Reservoir as part of the IWSS.

The Harris River provides significant freshwater input to the now largely brackish-saline Collie River system (DoW 2007a,c). Though upper Harris River is fresh[1], waters in the lower Harris River (below the Dam) are of marginal quality. There are environmental releases of water from Harris Reservoir to maintain the ecology of the Harris River downstream however, the EWR is only 11% of pre-dam flow (Welker & Streamtec 2000, WRM 2007), which is extremely small compared with most EWRs in the south-west, and is currently under review.

Burekup Weir and Lower Collie

Hydrologically, the Collie River downstream of Wellington Dam may be broken into an upper and a lower reach, respectively being, Wellington Dam to Burekup Weir, and Burekup Weir to the point of estuarine influence (WRM 2003). The Burekup weir diverts irrigation releases from Wellington Reservoir into the Collie River Irrigation District supply system. The weir is located ca. 12 km downstream from Wellington Dam (Figure 1) and has a negligible storage capacity (WEC 2001b, 2002). As a result of irrigation diversion at the weir, summer flows in the downstream Collie River are much reduced compared with their historical condition (WRM 2003). Winter flows are generated from 'local' sub-catchment runoff (*i.e.* downstream of Wellington Dam), with some flow from above Burekup Weir when it overtops. Significant flow over the weir is also generated by winter-spring scour release of saline water from Wellington Dam. Salinity in the Lower Collie between the weir and the point of estuarine influence ranges from marginal to brackish.

Henty Brook

Henty Brook is another important freshwater tributary of the Lower Collie. The upper reaches of the brook are located within state forest, though the majority of the catchment drains cleared farmlands. The brook joins the Collie River near the township of Burekup (Figure 1). There are current and potential new small storage developments along the brook with a current estimated total yield of ~5 - 10 GL/yr (DoW 2007a). Most of the dams along the brook are located on private property in the upper and middle reaches(WEC 2002). Estimated total storage capacity of these private dams is ca. 1.2 GL (WEC 2002). Water use is mostly for stock, flood irrigation of pasture for a dairy, and irrigation of small vineyards and domestic gardens.

Summer flows in the lower reaches of Henty Brook have historically been supplemented by losses/releases from the irrigation channel downstream of Lennard Road (east of South Western Highway) (WEC 2002). Waters in the brook upstream of South Western Highway tend to be fresh, while west of the Highway they are increasingly marginal.

Aims of the Study

Specific aims of the current study were to:

- Describe the range of selected suites of ecological values of aquatic, semi aquatic and riparian environments at the four reaches (see section on Field Sampling for tabulation of values to be surveyed);
- Provide a qualitative description of the water-dependence of each identified value and the probable tolerance to changes in the flow regime.

Identification of water-dependent ecological values for which flows are to be determined was achieved through:

i). a literature review, followed by
ii). targeted sampling to fill any knowledge gaps.

[1] Fresh <500 mg/L (<90 mS/m); marginal 500 - 1,000 mg/L (90-200 mS/m); brackish 1,000-3,000 mg/L (200-880 mS/m); saline 3,000-5,000 mg/L (880-5,000 mS/m); hypersaline >35,000 mg/L (>5,000 mS/cm) (ANZECC & ARMCANZ 2000).

This approach avoids duplication of effort as a result of resurveying the same area for values already well documented in the literature. Based on occurrence or likely occurrence of key water-dependent species, literature and expert knowledge of water requirements was used to detail response to flow modifications. Biology and life history of taxa were considered, including aspects such as preference for seasonal or perennial flows, habitat requirements, diet, and timing of breeding and migration.

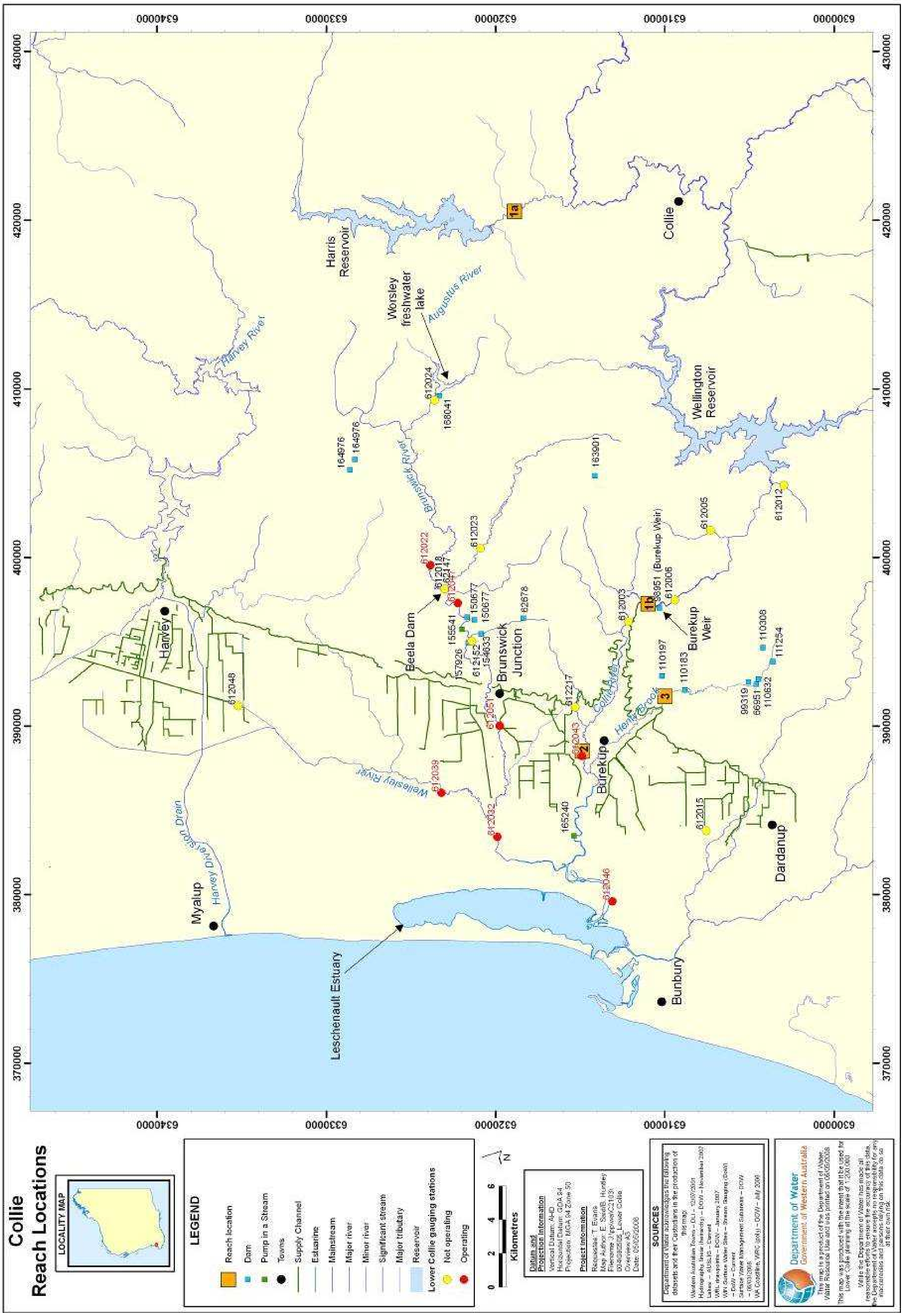

Figure 1. Location of study reaches within the Collie River catchment (map courtesy DoW).

LITERATURE REVIEW

SUMMARY OF PREVIOUS STUDIES

There have been a number of previous surveys of the aquatic biology within the Upper and Lower Collie, the majority of which were undertaken as part of EWR and EWP assessments between 1998 and 2008. There is a dearth of published scientific literature for the study area. A list of prior studies is provided in Table 1 and further discussion given in the relevant sub-sections below. Of particular note are concerns raised by Storey (2003) and Beatty and Morgan (2005) in regard to conservation of fish populations downstream of the Harris and Wellington dams (see section 'Fish and Crayfish, below). Beatty and Morgan (2005) found few native nightfish or western minnows downstream of the Harris Dam, while Storey (2003) found few pygmy perch downstream of Wellington Dam. This raises the issue of the adequacy of EWPs for conservation of local populations (and hence biodiversity) downstream of the dams.

Harris River and East Branch EWRs

In the Upper Collie, WEC and Streamtec (2000) detailed EWRs of the Harris River and lower East Branch using historic data collected by Streamtec (1987-1999). Streamtec (1987-1997) monitored annual and seasonal changes in aquatic macroinvertebrates, fish and *in situ* physico-chemistry before (1987- 1989) and after commissioning (1991-1993, 1997) of the Harris Dam. Data were collected from 3 sites on the Harris River (1 upstream and 2 downstream of the dam) and one site on the tributary Scar Road Creek. Streamtec (1999) conducted opportunistic visual surveys of fish at five sites in the Harris Reservoir and three sites on unspecified tributary streams for the (as then) proposed Harris-Stirling Pumpback Scheme. As part of the EWR study, WEC and Streamtec (2000) also undertook foreshore condition surveys at 13 sites along the lower Harris River and lower East Branch in June 1999, and channel morphology surveys at 7 sites between December 1999 and February 2000. The February 2000 channel morphology survey was conducted during an experimental release from the Harris Dam.

The adequacy of subsequent EWPs for the Harris River was assessed by Beatty & Morgan (2005) through a study of recruitment, abundances and biology of fish and crayfish species present. Beatty and Morgan (2005) surveyed 6 sites in the Harris River (3 above the Harris Reservoir and 3 sites downstream, below Norm Road) during October 2004 and February-March 2005.

EWRs for the upper East Branch were later evaluated by WRM (2007) based on key water-dependent ecological values of 4 reaches in the East Branch (2 upstream and 1 downstream of the unregulated Bingham River), and one in the Bingham River (near Bingham Gauging Station). WRM (2007) assessed foreshore condition and sampled water quality, aquatic macroinvertebrates and fish at 15 sites during late February 2006. WRM (2007) also reviewed existing EWRs and EWPs for the lower East and South branches. In 2008, WRM surveyed the fish, crayfish and aquatic invertebrates of Boronia and Snake gullies, tributaries of the lower East Branch. The survey formed the basis of EWR determinations for Boronia Gully (WRM 2009).

South Branch EWRs

EWRs and EWPs for the Collie River South Branch were determined by WEC and Streamtec (2001b). The focus for this study was 7 major pools affected by groundwater drawdown. WEC and Streamtec (2001b) used baseline macroinvertebrate data of Halse *et al.* (1999), gathered at the pools during spring 1998 and autumn 1999, together with fish and crayfish data of Morgan (1995), recorded over summer 1994/95, and foreshore condition data of Froend *et al.* (2000), collected in August 2000. Froend *et al.* (2000) also assessed foreshore condition along the East Branch.

Lower Collie and Henty Brook EWRs

Streamtec (2000) made preliminary determinations of the EWRs of the Lower Collie River and Henty Brook in 1999. The EWRs were based on field surveys of 17 sites in the Collie River (above the Burekup Weir, below the Burekup Weir and at Rose Road) and 5 in Henty Brook, conducted between September and December 1999. Surveys included foreshore assessments and macroinvertebrate sampling (Streamtec 2000). These preliminary EWRs formed the basis of 'first round' EWP determinations by Welker and Streamtec (2001a, 2002). Re-assessment of the EWRs of fish and riparian vegetation in the Lower Collie was subsequently undertaken by Storey (2003) and Syrinx (2003), respectively, as part of an EWR review by the Water & Rivers Commission (now DoW) (Hardcastle *et al.* 2003). Fish were sampled at 8 locations in the main channel in March 2003 (4 between Wellington Dam and Burekup Weir and 4 between Burekup Weir and the Australind bypass) (Storey 2003). Vegetation was survyed at 15 transects in March 2003 (10 between Wellington Dam and Burekup Weir, 3 at the foothills of the Darling Escarpment and 2 on the Swan Coastal Plain) (Syrinx 2003). WRC (2003) also re-surveyed channel morphology at 10 locations corresponding to vegetation transects.

The aquatic fauna of Henty Brook was also surveyed by WRM (2006a) in November 2005, as part of an Environmental Impact Assessment for proposed mineral sands mining by Iluka Resources Limited at Burekup. WRM (2006a) surveyed aquatic macroinvertebrates, fish, physico-chemistry and foreshore condition at 3 sites immediately east of South Western Highway.

Published Scientific Research

Published scientific research on the aquatic fauna and flora of the Upper and Lower Collie is limited, though there are several studies on secondary salinisation that indirectly address ecological values of riparian vegetation in the Upper Collie. The most recent of these is Lymbery *et al.* (2003) who examined the effects of secondary salinisation on riparian plant communities in three experimental catchments (Ernies, Dons and Lemon) in state forest along the Collie River East Branch. The study was conducted in June 2001 and involved replicate quadrat sampling within each of three transects in each catchment.

Pen and Potter (1990, 1991a,b,c,d, 1992) investigated the biology of three native and one introduced freshwater fish species resident in the Collie River South Branch. Pen and Potter (1990, 1991a,b,c,d, 1992) sampled 14 sites along the main river and 4 sites in tributary creeks at 4-6 week intervals during 1984-1986 and 1988.

Thirty-five sites within the Upper and Lower Collie were also sampled as part of a program to develop a biomonitoring system for rivers based on macroinvertebrates (First National Assessment of River Health (FNARH)). The program was co-ordinated by the Department for Conservation and Land Management (now Dept. for Environment and Conservation; DEC). Macroinvertebrates were sampled seasonally (autumn and spring) from 1994 to 1999 and data used to derive simple predictive models of river health, *i.e.* AusRivAS models (Kay *et al.* 2000, Halse *et al.* 2002).

Table 1. Previous studies of aquatic biology and ecological values of the Lower Collie (including Henty Brook) and Upper Collie (including the Harris and Bingham rivers and Boronia Gully).

SUB-CATCHMENT	STUDY NAME	STUDY DATE
UPPER COLLIE		
Harris River	Monitoring the adequacy of EWPs for fish and crayfish communities of Samson Brook, Harvey River and Harris River. Prepared for Water Corp. by S.J. Beatty & D.L Morgan (Centre for Fish &Fisheries Research, Murdoch Univeristy), 2005.	2004-05
Harris River	Adaptive Management of EWPs: Harris River immediately downstream from the Harris River Dam. Prepared for Water Corp. by Streamtec Pty Ltd, 2003.	2003
Harris River	EWRs: Harris River and East Branch of the Collie River (downstream of the confluence) to the South Branch. Prepared for Water Corp. by Welker Environmental Consultancy and Streamtec Pty Ltd, 2000.	2000
Harris River	Freshwater Fish of the Harvey and Harris River Catchments: An Assessment of Translocation Scenarios. Prepared for Water Corp. by Streamtec Pty Ltd, 1999.	1998
Harris River	Harris River Study: Macroinvertebrate Monitoring Pre and Post-Dam Construction. Prepared for the Water Authority of Western Australia (now Water Corp.) by Streamtec Pty Ltd, 1997.	1987-97
Harris River	AusRivAS Bioassessment: Macroinvertebrates. Co-ordinated by DEC.	1994-99
Harris River	ERMP for the Harris Dam. Prepared for the Water Authority of Western Australia by Dames & Moore, 1985.	1985
Collie River East Branch & Bingham River	Preliminary EWRs of the Collie River East Branch: risk assessment of salinity mitigation diversion scenarios. Prepared for DoW by Wetland Research & Management, 2007.	2006
Collie River East Branch	Effects of salinisation on riparian palnt communities in experimental catchments on the Collie River, Western Australia. A.J. Lymbery, R.G. Doupé & N.E. Pettit (Lymbery *et al.* 2003).	2001
Collie River East Branch & Bingham River	AusRivAS Bioassessment: Macroinvertebrates. Co-ordinated by DEC.	1994-99
Collie River East Branch & South Branch	Riparian Vegetation Survey of the Collie River South and East Branches. Prepared for Welker Environmental Consultancy by R. Froend, N. Petite & B. Franke (Centre for Ecosystem Management, Edith Cowan University), 2000.	2000
Collie River South Branch	EWPs: South Branch of the Collie River downstream from Western 5 open cut. Prepared for WRC by Welker Environmental Consultancy and Streamtec Pty Ltd, 2001.	2001
Collie River South Branch	Macroinvertebrate monitoring in the Collie River. Prepared for WRC by S. Halse,W. Kay, M. Scanlon & M.J.B. Smith (CALM - now DEC), 1999.	1998-99
Collie River South Branch	AusRivAS Bioassessment: Macroinvertebrates. Co-ordinated by DEC.	1994-99
Collie River South Branch	Distribution, identification and biology of freshwater fish in the south-western Australia. Records of the Western Australian Museum.. D.M. Morgan, H.S. Gill & I.C. Potter (Morgan *et al.* 1998).	1994-96
Collie River South Branch	The freshwater fish and fauna of the pools of the South Branch of the Collie River, during a period of extremely low water levels. Prepared for Water Authority of Western Australia by D.M. Morgan, H.S. Gill & I.C. Potter (Centre for Fish &Fisheries Research, Murdoch Univeristy).	1995
Collie River South Branch	Biology of the nightfish, western minnow and western pygmy perch. L.J. Pen & I.C. Potter (Pen & Potter 1990, 1991a-c).	1984-88
Collie River South Branch	Studieson reproduction and growth of mosquitofish and of red fin perch. L.J. Pen & I.C. Potter (Pen & Potter 1991d, 1992).	1984-86
Boronia Gully	EWRs of Boronia Gully. Prepared for Strategen Pty Ltd by Wetland Research & Management, 2009.	2008
LOWER COLLIE		
Lower Collie River	Synthesis report. Lower Collie River EWRs review: stream morphology, riparian vegetation and fish passage. Prepared for WRC by K. Hardcastle, T. Rose, M. Pearcy & A. Storey, 2003.	2003
Lower Collie River	Wellington below - EWR review: fish community including migration requirements. Prepared for WRC by Wetland Research & Management, 2003.	2003
Lower Collie River	Riparian vegetation requirements - Collie River. Prepared for WRC by Syrinx Environmental Pty Ltd, 2003.	2003

SUB-CATCHMENT	STUDY NAME	STUDY DATE
Lower Collie River & Henty Brook	Lower Collie River and Henty Brook Preliminary EWPs. Prepared for WRC by Welker Environmental Consultancy and Streamtec Pty, 2001.	2001
Lower Collie River & Henty Brook	Lower Collie River, including Henty Brook, EWRs. Prepared for WRC by Streamtec Pty Ltd, 2001.	1999
Henty Brook	AusRivAS Bioassessment: Macroinvertebrates. Co-ordinated by DEC.	1994-99
Henty Brook	Burekup Project: Baseline Aquatic Biology and Water Quality Study. Prepared for Iluka Resources Limited by Wetland Research & Management, 2006.	2005

WATER-DEPENDENT ECOLOGICAL VALUES

Riparian Vegetation

The general vegetation systems of the Collie catchment have been described by a range of authors including Speck (1958), Smith (1952), McArthur and Bettenay (1960) and Heddle *et al.* (1980). Vegetation of the upper Harris River catchment was also described by Dames and Moore (1983) as part of Environmental review process for construction of the Harris Dam. Detailed vegetation and floristic surveys have more recently been carried out as part of a land classification system developed by Mattiske and Havel (1998) for conservation planning in south-western Australia. Mattiske and Havel (1998) produced 1: 250 000 scale maps of 315 vegetation complexes, including one mapping unit for lakes and open water.

Remnant riparian vegetation along the Harris River and along the Collie River, between the Harris River confluence and Burekup weir, is typically dominated by jarrah (*Eucalyptus marginata*)-marri (*Corymbia calophylla*) open forest on the upper and middle valley slopes and by jarrah-marri-yarri (*E. patens*) open forest on the lower slopes. Common understorey trees and shrubs include bull banksias (*B. grandis*), sheoaks (*Allocasuarina fraseriana*) and peppermints (*Agonis linearifolia*) over thickets of *Astartea fasicularis*. In lowland reaches, the jarrah-marri-yarri forest grades into fringing woodlands of flooded gum (*E. rudis*) and swamp paperbark (*Melaleuca rhaphiophylla*). A narrow fringe of dense twigrush (*Baumea* sp.) and sedges (*Leptocarpus* sp., *Lepidosperma* sp.) often line the waters edges. Typical aquatic plants include water ribbon (*Triglochin* sp.), pond weed (*Potamogeton tricarinatus*) water milfoil (*Myriophyllum* sp.).

Harris River Foreshore Assessments

Within the current study area, riparian vegetation along the Harris River was detailed by Dames and Moore (1985) in their *Environmental Review and Management Programme* for construction of the Harris Dam. In 1999, WEC & Streamtec (2000) surveyed the riparian vegetation of the Harris River below the dam and along the lower East Branch using the foreshore condition assessment methods of Pen and Scott (1995). WEC and Streamtec (1999) assessed 13 sites; one site on Scar Creek tributary, 6 sites between the Harris Dam and the confluence with the East Branch and 6 along the lower East Branch. One site ("Norms Bridge") was located within Reach 1a of the current study (refer Figure 1). Local vegetation condition was classed as near-pristine (condition category A2) along the Harris River below the dam, grading to slightly disturbed (A3) below Norm Bridge and downstream to Stubb's Farm (WEC & Streamtec 2000). In the lower East Branch, foreshore was assessed as degraded (B1-B3) due to historic clearing for agriculture, stock access and construction of drains for flood control (WEC & Streamtec 2000). The study found little evidence of erosion at any of the sites surveyed, including the reach immediately below Norm Road.

Lower Collie and Henty Brook Foreshore Assessments

In the Lower Collie, Streamtec (2000) assessed foreshore condition at 17 sites along the main chanel of the lower Collie River and 5 sites along Henty Brook between September and December 1999. Details of the sites were not reported, so locations relative to sites surveyed for the current study could not be ascertained. In the upper catchment below Wellington Dam, Streamtec (2000) evaluated foreshore conditions as near-pristine (A1-A2), becoming degraded (B1-B3) in agricultural lands in the mid-reaches with some localised erosion (C). The upper reaches of Henty Brook were also classified as degraded (B1-B3) and lower reaches substantially so. Immediately upstream from the confluence with the Collie River, bank slumping and rilling and channel incision along the brook had caused significant erosion and lead to in-filling (aggradation) of deep pools and a loss of aquatic habitat (Storey 2000, WEC 2002). Streamtec (2000) also noted there was little successful recruitment of riparian vegetation in downstream reaches of the brook. Overall, Streamtec (2000) considered many parts of the lower Collie River and Henty Brook to be so ecologically degraded that restoration of flow below impoundments would be of limited ecological benefit without extensive catchment restoration. In 2005, WRM also assessed foreshore condition east of South Western Highway on Henty Brook (WRM 2006a) (Plate 1). The assessment was conducted at three sites over a 1-km reach with the downstream end located ca. 1-km east of the Highway. The upper section was categorised as D1, actively eroding, deeply incised (to ~4 m) and in very poor environmental condition. The lower section was graded C2.


Fringing flooded gums and peppermints with an understorey dominated by pasture grasses (C2)


Large woody ± perpendicular to channel flow (C2)


Eroded (slumped) bank on meander bend of incised Channel (C2)


Degraded riparian vegetation with sparse remnant overstorey along uniform sand-bed channel (D1)

Plate 1. Representative foreshores along Henty Brook east of the South Western Highway (from WRM 2006a).

WRC (2003) provide generalised descriptions and photographs of vegetation and channel morphology along the main channel of the lower Collie River between Wellington and the Australind bypass. The descriptions were based on foresheore condition assessment of 18 sites and encompass Reach 2 and Reach 3 of the current study (refer Figure 1). WRC (2003) describe the river reaches between Burekup Weir and Australind bypass as "exhibiting a downstream transition from a deep, steep-sided, forested valley, to more open valley with semi-cleared vegetation, to an incised, low gradient channel flowing across the coastal plain". Native riparian vegetation was categorised as reasonably intact and healthy below the weir, but reducing to a narrow, degraded belt supporting mainly weed species (*i.e.* willow, blackberry, pasture grasses) in the mid-reaches and lower reaches (Plate 1). In accord with Streamtec (2000), WRM (2003) considered the lower reaches (below Burekup Weir) to be most degraded and that the "effects of poor catchment management exceeded the physical attributes representing stream morphology that would have been maintained by natural flows or the current flow regime". The lower section was characterised by many infilled pools and areas of active erosion leading to a requirement for higher flows in this section to maintain natural scour and enhance river form. WRM (2003) considered the upper section (between Burekup Weir and Wellington Dam) to be self-maintaining in terms of channel geomorphology. Regular overtopping of the dam was thought to be critical for maintainenance of channel form in this reach, through flushing of pools *etc.*

Syrinx (2003) conducted detailed vegetation surveys of the lower Collie along 15 transectsbetween Wellington Dam and Australind bypass. The tansects were located in 10 different vegetation communities, representing three vegetation complexes. Riparian vegetation in the vicinity of Wellington Dam was found to be in very good to pristine condition (refer Plate 1); dominated by dense fringing rushes (*e.g. Baumea* spp., *Lepidosperma effusum*) with a dense to moderately dense stall shrub layer of *Astartea fascicularis*, grading into *Oxylobium lineare* and *Dodonaea viscosa* at higher elevation. The dense fringing rush communities were seen as a critical component of remnant riparian vegetation between Wellington Dam and Burekup weir. These were believed threatened by (then) proposed reductions in dry-season flow which may result in loss of fringing rush communities and subsequent undercutting of banks, loss of species on granite and sand islands, and increased weed invasion. Syrinx (2003) also considered that regeneration and recruitment of fringing rushes (*B. vaginalis*, *B. rubiginosa Meeboldina scariosa*) were at risk from reduced flows. Below Burekup weir, riparain vegetation was increasingly degraded with few mature trees, little or no recruitment of overstorey species and an understorey dominated by pature grasses and weeds (refer Plate 1).

River channel immediately below Burekup weir - healthy vegetation, and exposed bedrock and boulders in the channel (A1-A2)

Degraded riparian vegetation in the lower reach, with sparse, mature trees and no recruitment (C3)

Uniform, sand-bed river on the low gradient, coastal plain section of the lower reach (C1-C2)

A sediment slug in the main channel of the lower reach, which has been stabilised by vegetation (C2-C3)

Plate 2. Representative foreshores of the Lower Collie between Burekup weir and Australind bypass (from WRM 2003).

Macroinvertebrates

Available information on the aquatic invertebrate communities of the Upper and Lower Collie is limited to Streamtec (1987-1997) for the Harris River, WRM (2007) for the East Branch and Bingham River and WRM (2006a) for Henty Brook. A number of sites within the Collie basin were also sampled as part of a program to develop a biomonitoring system for rivers based on macroinvertebrates (First National Assessment of River Health (FNARH)) (Halse 1999, 2002, Kay *et al.* 2000). Included in the sampling was one site on the Harris River, one on the Bingham River, 8 each on the Collie River East and South branches, and one on Henty Brook (Lennard Road). The study was based on the AusRivAS approach, which uses family-level taxonomic identifications of macroinvertebrates to assess river health. The Collie basin was classified as 'severely impaired' based on its AusRivAS score, however, condition was uneven across the catchment, with the final score being influenced by the location of sites (Halse *et al.* 2002). Though family-level was used for analyses, all fauna were initially identified to the lowest taxon possible (usually species-level). This raw data was not sourced for the current review but is available upon request from the DEC Wetland Research office at Woodvale, Western Australia.

Harris River

The Harris River study by Streamtec (1987-1997) involved replicate quantitative sampling of benthic macroinvertebrates (*i.e.* ≥250 µm in size) using a Surber sampler (area 0.0625 m^2). Seasonal sampling ('spring' & 'summer') was conducted annually from 1987 to 1993 and in spring 1997. Four sites were surveyed: one site at Mistley Road in forested catchment above the Harris Reservoir, one on Scar Road Creek tributary below the dam wall, one on Harris River immediately below the dam wall, and one immediately upstream of the confluence with the Collie River at Stubbs Farm. A total of 8,000 individuals were collected, representing 72 species of macroinvertebrate with an average of ca. 20 species per site. Univariate (ANOVA) and multivariate analyses (TWINSPAN & PATN) indicated no significant differences in macroinvertebrate community structure due to impoundment (Streamtec 1997). The composition of functional feeding[2] groups at each site was dominated by 'collectors', which was considered typical of forested streams world-wide (Streamtec 1997). Fauna was dominated by Insecta (70%) with Crustacea and Mollusca only a minor component of the fauna (Table 2). Species recorded with limited distributions included the tiny native freshwater snail *Glacidorbis occidentalis*, the stonefly *Riekoperla occidentalis* and the Priority 4 listed freshwater mussel *Westralunio carteri* (Streamtec 1997). *W. carteri* is currently classified by the Department of Environment and Conservation (DEC) as a Priority 4 species, indicating they are in need of monitoring. Streamtec (1997) provide a list of all taxa recorded but the list is not site specific.

A comparison with the known macroinvertebrate fauna for the Collie River East Branch and Bingham River is provided in Table 2. Because of differences in sampling technique and time of year, comparisons should be viewed as indicative only. WRM (2007) surveyed the macroinvertebrate fauna of the East Branch and Bingham River on one occasion in late February 2006. A total of 15 sites were surveyed across 4 reaches in the East Branch and one in the Bingham River. Collecting techniques differed from Streamtec (1987-1997) in that semi-quantitative sweep netting was used to collect from a range of habitats, rather than benthic Surber sampling. WRM (2007) recorded a total of 91 species from the East Branch with an average of 44 species per site, while the Bingham had a total species richness of 72 for the one reach sampled. Overall, the faunal assemablages were similar to those recorded for the Harris. The most notable differences were the dominance of 'predators' and far fewer Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddis-flies) species in the East Branch and in the Bingham River (Table 2). This likely reflected low habitat diversity and lack of fringing and in-stream vegetation. Ephemeroptera, Plecoptera and Trichoptera are often referred to as EPT taxa. Species within these orders tend to be more sensitive to disturbance and hence used as indicators of river health (Marchant *et al.* 1995, Marshall *et al.* 2001).

Henty Brook

WRM (2006a) surveyed the macroinvertebrate fauna of Henty Brook on one occasion in late November 2005. A total of 3 sites were surveyed on pastoral lands immediately east of South Western Highway. Semi-quantitative sweep nets were used to collect fauna from all in-stream habitats present, *i.e.* benthos, macrophytes, draped vegetation and open water. Invertebrate assemblages were similar to those recorded for the Harris River (Streamtec 19997), East Branch and Bingham River (WRM 2007), with an abundance and diversity of Insecta (76%), particularly Diptera (Table 2). WRM (2006a) recorded a total of 79 species for Henty Brook with an average 42 species per site. The majority of species were cosmopolitan and none were considered rare or restricted in distribution. Like the East Branch and Bingham River, the fauna was dominated by 'predators' and there were fewer EPT taxa than in forested Harris River reaches (refer above).

[2] Functional feeding groups: 'shredders' feed on coarse particulate matter (CPOM > 1 mm); 'collectors' feed on fine particulate matter (FPOM < 1 mm); 'filterers' filter suspended particles from the water column and are often viewed as a subset of collectors; 'grazers' are those animals that graze or scrape algae and diatoms attached to the substrate; 'predators' capture live prey.

Table 2. Representative macroinvertebrate taxa previously recorded for the Harris River (Streamtec 1997), Collie River East Branch (WRM 2007), Bingham River (WRM 2007) and Henty Brook (WRM 2006a). The taxa list given for the Harris River is not strictly comparable to others shown as different methods were used by Streamtec (1997) to those of the WRM (2006a, 2007) studies. The total number of 'species' includes all taxa listed in the respective studies and not just the representative taxa given in the table below.

MACROINVERTEBRATES	NUMBER OF 'SPECIES'			
	HARRIS RIVER	COLLIE EAST BRANCH	BINGHAM RIVER	HENTY BROOK
MOLLUSCA				
Gastropoda (*Glacidorbis, Ferrisia, Glyptophysa*)	1	1	4	2
Bivalvia (*Westralunio*)	1	0	0	0
CRUSTACEA				
Ostracoda (brine-shrimps)	>2	>2	>2	>2
Copepoda (shield shrimp)	>2	>2	>2	>2
Isopoda (phreatoicids)	1	0	0	0
Amphipoda (*Perthia*, *Austrochiltonia*)	2	1	1	2
Decapoda (*Cherax*, Palaemonetes)	1	3	3	0
INSECTA				
Ephemeroptera (mayflies)				
Leptophlebiidae (*Nyungara, Bibulmena*, *Neboissophlebia*)	3	0	0	1
Baetidae (*Baetis*, *Cloeon*)	2	1	1	1
Caenidae (*Tasmanocoenis*)	1	1	1	1
Odonata (dragonflies & damselflies)				
Zygoptera (*Austroagrion, Austrolestes, Ischnura)*	3	4	2	2
Anisoptera (*Hesperocordulia*, *Lathrocordulia*, *Synthemis*)	8	6	7	5
Plecoptera (stoneflies)				
Griptopterygidae (*Leptoperla*, *Newmanoperla*, *Riekoperla*)	3	0	0	0
Hemiptera (true bugs)				
Corixidae (*Agraptocorixa, Sigara, Micronecta*)	0	6	1	3
Notonectidae (*Anisops*)	0	1	0	1
Coleoptera (aquatic beetles)				
Dytiscidae (*Sternopriscus*)	1	14	10	7
Hydrophilidae (*Paracymus, Berosus, Enochrus*)	1	4	2	5
Gyrinidae (Macrogyrus, Aulonogyrus**)**	1	2	2	2
Diptera (two-winged flies)				
Chironomidae (non-biting midges)	32	18	14	11
Culicidae (mosquitoes)	0	0	0	1
Ceratopogonidae (biting midges)	>2	>2	>2	>2
Simulidae (black-flies)	2	0	0	2
Tipulidae (crane flies)	1	0	0	1
Empididae (dance flies)	1	0	0	1
Trichoptera (caddis-flies)				
Ecnomidae (*Ecnomina*, *Ecnomus*)	2	1	0	1
Leptoceridae (*Triplectides*, *Notolina*, *Condocerus*)	4	3	3	2
Hydrobiosidae (*Taschorema*, *Apsilochorema)*	2	0	0	1
Hydroptilidae (***Acritoptila,*** *Oxyethira*)	4	0	1	1
Hydroropsychidae (*Smicrophylax*, *Cheumatopsyche*)	1	0	0	1
Philopotamidae (*Hydrobiosella*)	1	0	0	0
Total number of 'species' recorded	**72**	**91**	**72**	**79**

Fish and Crayfish

Eight species of native fish (Table 3) and three species of native freshwater crayfish (Table 4) have been recorded from the Collie system.

Table 3. Fish species previously recorded from the Upper and Lower Collie. Introduced species are marked with an asterix.

SCIENTIFIC NAME	COMMON NAME	PREVIOUSLY RECORDED FROM:	PREVIOUSLY RECORDED BY:
Bostockia porosa	Nightfish	* Harris River (upper & lower reaches) * Collie River East Branch (lower & upper reaches) * Collie River East Branch (Boronia Gully) * Collie River South Branch (above Schultz's weir) * Lower Collie River (from Wellington Dam to Australind bypass) * Henty Brook	* Beatty & Morgan 2005 * WRM 2007 * WRM 2009 * Pen & Potter 1990; Morgan *et al.* 1998 * WRM 2003 * WRM 2006a
Galaxias occidentalis	Western minnow	* Harris River (upper & lower reaches) * Collie River East Branch (lower & upper reaches & Bingham River) * Collie River East Branch (Boronia Gully) * Collie River South Branch (above Schultz's weir) * Lower Collie River (from Wellington Dam to base of Burekup Weir)	* Streamtec 1997; Beatty & Morgan 2005 * WRM 2007 * WRM 2009 * Pen & Potter 1991a,b; Morgan *et al.* 1998 * WRM 2003
Edelia vittata	Western pygmy perch	* Harris River (upper & lower reaches) * Collie River East Branch (upper reaches & Bingham River) * Collie River South Branch (above Schultz's weir) * Lower Collie River (from Burekup Weir to Australind bypass) * Henty Brook	* Beatty & Morgan 2005 * WRM 2007 * Pen & Potter 1991c; Morgan *et al.* 1998 * WRM 2003a * WRM 2006a
Tandanus bostocki	Cobbler	* Bingham River * Lower Collie River (from Burekup Weir to Australind bypass)	* WRM 2007 * WRM 2003a
Afurcagobius suppositus	Big headed goby	* Lower riverine/estuarine parts of the Collie River system	* Morgan unpub. data
Pseudogobius olorum	Swan River goby	* Lower Collie River (from Burekup Weir to Australind bypass)	* WRM 2003a
Leptatherina wallacei	Western hardyhead	* Lower riverine/estuarine parts of the Collie River system	* Morgan unpub. data
Geotria australis	Pouched lamprey	* Lower riverine/estuarine parts of the Collie River system	* WA Museum records 1912, 1916 (cited by Morgan *et al.* 1998)
**Gambusia holbrooki*	Eastern mosquitofish	* Harris River (upper & lower reaches) * Collie River East Branch (upper & lower reaches & Bingham River) * Collie River South Branch & Wellington Dam * Lower Collie River (from Burekup Weir to Australind bypass)	* Streamtec 1997, Beatty & Morgan 2005 * WRM 2007 * Pen & Potter 1991d; Morgan *et al.* 1998 * Storey 2003
**Perca fluviatalis*	Red fin perch	* Harris River (upper & lower reaches) * Collie River East Branch (upper reaches & Bingham River) * Collie River South Branch & Wellington Dam * Lower Collie River (from Wellington Dam to Burekup weir)	* Streamtec 1997, Beatty & Morgan 2005 * WRM 2007 * Pen & Potter 1992; Morgan *et al.* 1998 * Storey 2003
**Onchorhynchus mykiss*	Rainbow trout	* Harris River (upper reaches) * Lower Collie River (at base of Burekup Weir)	* Streamtec 1997 * Storey 2003

Table 4. Crayfish species previously recorded from the Upper and Lower Collie.

SCIENTIFIC NAME	COMMON NAME	PREVIOUSLY RECORDED FROM:	PREVIOUSLY RECORDED BY:
Cherax quinquecarinatus	Gilgie	* Harris River (upper & lower reaches) * Collie River East Branch (upper & lower reaches & Bingham River) * Collie River East Branch (Snake Gully) * Collie River South Branch (main pools) * Henty Brook	* Beatty & Morgan 2005 * WRM 2007 * WRM 2009 * Morgan *et al.* 1995 * WRM 2006a
Cherax cainii	Marron	* Harris River (upper & lower reaches) * Collie River East Branch (lower reaches & Bingham River) * Collie River South Branch (main pools)	* Beatty & Morgan 2005 * WRM 2007 * Morgan *et al.* 1995
Cherax preissii	Koonac	* Harris River (upper reaches) * Collie River East Branch (Snake Gully)	* Beatty & Morgan 2005 * WRM 2009

Previous surveys for fish have largely focused on the Upper Collie and the literature search found few studies detailing the fish fauna of the Lower Collie. None of the species reported to date are considered rare or retricted in distribution. However, lampreys which were once present in the lower Collie River have not been recorded since the early 1900s and local populations of nightfish, western pygmy perch and western minnows may be under threat from altered flow regimes. The flow requirements of fish and crayfish species have been discussed in detail by Storey (2003), Beatty and Morgan (2005), WRM (2006-2009) and WRM and DoW (2007).

Harris River

In the Harris River, Streamtec (1997) recorded three native freshwater fishes (western minnows, pygmy perch and nightfish) and three introduced fishes (mosquitofish, redfin perch and rainbow trout). The fish were collected using a modified seine net stretched across the width of the river coupled with visual observation. Streamtec (1997) sampled 4 sites on 5 occasions between 1987 and 1997; one site upstream of the dam at Mistley Road and three sites downstream – upstream of Norm Road, Stubb's Farm ca. 8 km below the dam, and Scar Road Creek tributary. No fish were recorded from the Mistley Road site and native nightfish and pygmy perch were only recorded from Scar Road Creek (Streamtec 1997).

More comprehensive studies of fish biology in the Harris River by Beatty & Morgan (2005) revealed a similar suite of species to that reported by Streamtec (1997), however no rainbow trout were recorded. Beatty and Morgan (2005) surveyed 6 sites in the Harris River (3 above the Harris Reservoir and 3 sites downstream, below Norm Road) during October 2004 and February-March 2005. Sampling involved semi-quantitative electrofishing coupled with seine netting and larval traps. Western minnows, pygmy perch and night fish were found to be present both upstream and downstream of Harris Dam, though nightfish were represented by a single individual. Beatty and Morgan (2005) considered populations of nightfish downstream of the dam were potentially un-sustainable. They also suggested that relatively low abundances and low level of recruitment in western minnows downstream of the dam may be related to inadequate EWPs for fish migration and reproduction. Crayfish were also surveyed. Marron and gilgies were collected both upstream and downstream of the dam, while koonacs were recorded from more temporary upper reaches.

WRM (2007) sampled the Collie River East Branch upstream of the confluence with the Harris River, but did not sample the Harris River itself. It is likely that freshwater species present in the East Branch might also occur in the Harris River. WRM (2007) sampled 15 sites across 4 reaches during late February 2006. Sampling principally involved semi-quantitative electrofishing but, dependent on habitat, also included sweep netting, fyke nets, box traps and direct observation. The fish fauna recorded was similar to that listed by Beatty and Morgan (2005) for the Harris River with the addition of native freshwater cobbler.

In November 2008, WRM sampled fish and crayfish at 3 sites along Boronia and Snake Gully, tributaries of the lower East Branch (WRM 2009). Four species were recorded: nightfish and western minnows from Boronia Gully, and gilgies and koonacs from Snake Gully.

Morgan *et al.* (1998) reviewed the known distribution of freshwater fishes in south-western Australia, including the Collie system, but did not sample the lower Collie, only including records from the southern branch of the Collie River above Wellington Dam. Included in the review were data gathered by Morgan *et al.* (1995) from South Branch pools and data from fish biology research conducted by Pen and Potter (1990, 1991a-d, 1992) in the 1980s. Species recorded included western minnow, nightfish, western pygmy perch, mosquitofish, redfin perch, marron and gilgies.

WEC & Streamtec (2001) reported anecdotal evidence from community workshops that numbers of larger marron and gilgies in pools of the Collie River South Branch have declined over the past ten years.

Lower Collie and Henty Brook

In the Lower Collie, baseline fish and crayfish surveys by Storey (2003) documented the presence of 5 native fish species, 3 introduced fish species and two species of native freshwater crayfish (marron & gilgies). Most fish species were well represented by a number of age classes. The only fish additional to those listed above for the Upper Collie was the estuarine Swan River goby. The sampling was conducted in March 2003 using electrofishing and visual observation at a total of 8 sites in the main channel (4 sites between Wellington Dam and Burekup Weir and 4 between Burekup Weir and Australind bypass). Sites included two in each of Reach 2 and Reach 3 of the current study. Storey (2003) noted there was an absence of native pygmy perch between Wellington Dam and Burekup weir and very few pygmy perch in reaches downstream of the weir. This was considered an issue of concern in terms of the conservation of this species in the Collie river system (Storey 2003).

Morgan *et al.* (1998) summarised the W.A. Museum records of fish, which document the presence of adult pouched lampreys in the lower Collie River in 1912 and 1916, but this species has not been recorded since and is no longer likely to occur due to habitat alteration (WRM 2007). Morgan (unpublished data), sampled tributaries of the Brunswick River, which is within the Collie River system, and did record ammocoetes of the pouched lamprey. However, the literature review found no recent published records of ammocoetes in the Collie River. The Swan River goby, western hardyhead and big headed goby also occur in the lower riverine/estuarine parts of the Collie River system (Morgan, unpub. data.).

In Henty Brook, WRM (2006a) recorded two species of native freshwater fishes and one species of crayfish from 3 sites surveyed on one occasion in November 2005. Species recorded included nightfish, western pygmy perch and gilgies. WRM (2006) survey methods were the same as used for the current study and surveyed sites were located immediately upstream from current study Reach 3.

Other Aquatic Fauna

Amphibians

Three species of frog have been documented as breeding within the study area. These include Glauert's froglet, the squelching froglet and the slender tree frog (WRM 2006a, 2007) (Table 5). Frogs of an additional two species – quacking froglet and Lea's frog - were recorded along the Harris River prior to construction of the Harris Dam (Dames & Moore 1983). All are endemic to and common throughout the south-west. Preferred habitats of the froglets are temporary swamps, marshy areas, seeps and shallow bogs on the coastal plain. All species will breed following any rain (Tyler *et al.* 2000).

The slender tree frog is commonly found within dense cover of reeds and rushes along the edge of static or slowly moving waterbodies. Breeding occurs during spring with eggs being deposited in the water and attached to emergent aquatic vegetation (Tyler *et al.* 2000).

The study area lies within the known range of at least two other species; Gunther's toadlet *Pseudophryne guentheri* and the western green tree frog *Litoria moorei* (Bamford & Watkins 1983). All frogs need water during certain stages of their life cycle in which to lay eggs and for tadpoles to survive and metamorphose (WRM 2007).

Table 5. Other aquatic fauna recorded in recent scientific surveys of the Upper and Lower Collie.

SCIENTIFIC NAME	COMMON NAME	PREVIOUSLY RECORDED FROM:	PREVIOUSLY RECORDED BY:
FROGS			
Crinia insignifera	Sign-bearing or squelching froglet	* Collie River East Branch (Bingham River), * Henty Brook	* WRM 2007 * WRM 2006a
Crinia glauerti	Glauert's froglet	* Harris River * Henty Brook	* Dames & Moore 1983 * WRM 2006a
Crinia georgiana	Quacking froglet	* Harris River	* Dames & Moore 1983
Geocrinia leai	Lea's frog	* Harris River	* Dames & Moore 1983
Litoria adelaidensis	Slender tree frog	* Harris River * Henty Brook	* Dames & Moore 1983 * WRM 2006a
TORTOISE			
Chelodina oblonga	Long-necked tortoise	* Collie River East Branch (upper reaches & Bingham River)	* WRM 2007
WATERBIRDS			
Anas superciliosa	Pacific black duck	* Henty Brook	* WRM 2006a
Chenonetta jubata	Australian wood duck	* Henty Brook	* WRM 2006a
Tadorna tadornoides	Australian shelduck	* Henty Brook	* WRM 2006a
Threskiornis spinicollis	Straw-necked ibis	* Henty Brook	* WRM 2006a
Egretta novaehollandiae	White-faced heron	* Henty Brook	* WRM 2006a
Ardea ibis	Cattle egret	* Henty Brook	* WRM 2006a
Halcyon sancta	Sacred Kingfisher	* Henty Brook	* WRM 2006a
WATER RATS			
Hydromys chrysogaster	Rakali or water rat	* Collie River East Branch (upper reach at Coolangatta)	* WRM 2007

Reptiles

One aquatic reptile species, the long-necked tortoise *Chelodina oblonga*, has been recorded from the Collie River East Branch (Table 4) and local landowners report it as widely occurring throughout the Upper and Lower Collie. This species is endemic to the south-west of Western Australia, inhabiting both permanent and seasonal waterbodies. Where permanent water is available, long-necked tortoise may nest twice during the breeding season; *i.e.* in September-October and again in December-January. In seasonal systems, nesting typically only occurs during spring. Since tadpoles, fish, and aquatic invertebrates constitute a large part of their diet, tortoises tend to eat only when open water is present (WRM 2007).

There are a number of other reptile species likely to inhabit the riparian zone that can perhaps be regarded as semi-aquatic (WRM and DoW 2007). These are species that are reliant upon riparian vegetation for survival and tend to be limited to areas of damp soil. Species include the tiger snake *Notechis scutatus*, the mourning skink or western glossy swamp skink *Egernia luctuosa*, and the western three-lined or southwestern cool skink *Acritoscincus trilineatum*. All three species are believed largely restricted to the margins of waterways (WRM & DoW 2007). No dedicated surveys for these species have been conducted within the study area.

Waterbirds

The literature review found only one study (WRM 2006a) that listed waterbird species specific to the study area. WRM (2006a) opportunistically recorded waterbirds during macroinvertebrate and fish surveys of Henty Brook in 2005. Seven species were recorded (Table 5) including the cattle egret which are listed under JAMBA, CAMBA and CMS treaties and as such is protected under the commonwealth *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act).

Whilst waterbirds are more likely to frequent wetland systems, perennial reaches along larger rivers may be important as a drought refuge in summer. Waterbirds are dependent on aquatic systems as they provide habitat for feeding (they forage on a range of aquatic organisms, including plants, macroinvertebrates and fish), moulting, breeding and nesting (WRM 2007). Generally, rivers and water courses on the Swan Coastal Plain do not comprise important waterbird habitat, supporting only low numbers of a small suite of species (Storey *et al.* 1993).

Mammals

A number of species have been observed inhabiting the riparian zones of the Upper and Lower Collie. Landholders have reported the following species; brushtail possums (*Trichosurus vulpecular*), western ringtail possums (*Pseudocheirus occidentalis*), brush-tailed phascogales (*Phascogale tapoatafa*) and water rats (*Hydromys chrysogater*). Of these, water rats are the most closely associated with the river system (WRM 2007). Water rats are currently classified by the Department of Environment and Conservation (DEC) as a Priority 4 species, indicating they are in need of monitoring. The species occupies a wide variety of freshwater habitats, from inland waterways to lakes, swamps, and farm dams. Water rat activity is generally obvious since they often take prey to a favourite feeding platform, such as a log, rock, or stump, located close to the water, where remains of its food may be seen. Water rats build nests into banks near tree roots or in hollow logs. Inland populations, often associated with temporary water, can be highly unstable; water rats are subject to heat stress and captive animals are unable to survive high temperatures without large amounts of water (Watts & Aslin 1981).

There is little available data on the spatial distribution of water rats along the Collie River or its tributaries. Although not specifically surveyed, water rat feeding platforms were observed by WRM (2007) along the East Branch at Coolangatta (Table 5). WEC & Streamtec (2001) reported anecdotal evidence from community workshops that permanent pools of the South Branch also support water rats.

Carbon Sources / Processing

The importance of maintaining carbon (energy) links in regulated rivers has previously been summarised by WRM and DoW (2007). Carbon (energy) links exist both longitudinally within a river and between the river and its floodplain. Maintenance of these links can be vital to the protection of current ecological values as they form the basis of a river's food web and thus ecosystem function. There are three currently accepted models which describe carbon movement through freshwater systems:

1. River Continuum Concept (Vannote *et al.* 1980) – emphasises the longitudinal connection of upstream and downstream reaches *via* flow. Under this model, lower river reaches rely on fine particulate organic matter (carbon) derived from upstream terrestrial vegetation and transported downstream by river flows.
2. Flood-Pulse Concept (Junk *et al.* 1989) – emphasises the importance of river-floodplain connections. Under this model, aquatic ecosystems are driven by lateral inputs of organic matter from the floodplain during flood events. This model is typically applied to large floodplain rivers.
3. Riverine Productivity Model (Thorp & Delong 1995) – emphasises the importance of in-stream primary production (phytoplankton & benthic algae), and direct inputs from the adjacent riparian zone.

There has been only one study on the source and flux of carbon in the Collie River system. This was by Streamtec (2000) who used measurements of benthic metabolism and stable isotope analyses to provide preliminary estimates of productivity and trophic structure. Streamtec (2000) used Perspex metabolism chambers to measure the gross primary productivity (GPP) and respiration (R_{24}) of benthic substrates at four reaches; two in unspecified forested areas along the Harris River and Wellington Reservoir, one along the Collie River near Mt Lennard, and one in estuarine reaches of the lower Collie River. Results showed R_{24} > GPP in forested upper reaches, suggesting upland ecosystems were net consumers of carbon and therefore reliant on terrestrial input of carbon, *i.e.* "heterotrophic" (Odum 1956). Lower reaches had R_{24} < GPP, suggesting net production of carbon, *i.e.* "autotrophic".

Streamtec (2000) analysed carbon isotope 'signatures' of aquatic macroinvertebrates, algae and detrital material from four unspecified reaches; Harris River, Collie River, "Estuary" and Henty Brook. They concluded that carbon signatures of aquatic fauna in both the upper and the lower reaches reflected those of detrital sources from the upper catchment. Based on these and the productivity estimates, Streamtec (2000) concluded that the River Continuum Concept best defined the functioning of the Collie River. Streamtec (2000) recommended that an unregulated, constant flow from the forested regions (adjacent to the Wellington Reservoir) to the lower reaches would therefore be required to sustain downstream ecosystems. However, impoundment of rivers is known to disrupt the flow of carbon downstream, and with increasing distance, the Riverine Productivity Model likely plays a greater role. The Riverine Productivity Model predicts the relative contribution of in-stream algal carbon will increase in broad, open, shallow lowland reaches, particularly where riparian vegetation has been cleared. Streamtec (2000) also found that with increasing estuarine influence, the food-webs in the Lower Collie became more reliant on algal carbon.

FIELD SAMPLING

SITE LOCATIONS

Study reaches were selected by the DoW, being the reaches surveyed for channel morphology and development of hydraulic models. Within each of the four study reaches (Figure 1) six representative sites were selected for sampling to document ecological values. This would allow hydraulic analysis to target the observed ecological values for each reach. Each site consisted of a 40 - 50 m section of river, selected to represent a diversity of habitats (*i.e.* pools, riffles, backwaters, off-channel wetlands and riparian vegetation). GPS co-ordinates of sampling sites are provided in Table 6. Field surveys were conducted between 3 - 6 November 2008 and included:

- Qualitative assessment of riparian vegetation condition;
- *In situ* measurement of water quality;
- Semi-quantitative sampling for macroinvertebrates, crayfish and fish;
- Opportunistic surveys for frogs, tortoise, waterbirds and water rats.

Not all of the above values were assessed in all reaches. As per the project brief, ecological components were only surveyed where DoW indicated knowledge gaps existed for a specific reach or where DoW required additional baseline data (Table 7). The scope of work did not include fish or foreshore assessment surveys in Reach 1b or Reach 2, as it was considered these values were adequately documented for these reaches.

METHODS

Foreshore Condition and Water Quality

Bank, riparian vegetation and in-stream habitat condition were qualitatively evaluated using the foreshore condition assessment technique of Pen and Scott (1995) and WRC (1999). Sites were scored on the basis of bank condition, erosion, vegetation status and presence of weed species. An overall Condition category and Environmental Rating were then assigned to each site.

Riparian plant species assemblages were not identified for each site. Previous EWR studies have found difficulty in definitively determining the frequency and duration of inundation required by different plant species. This essentially reflects the lack of knowledge of flow requirements of riparian vegetation.

Until the specific flow requirements of riparian species are understood, such detailed vegetation surveys are unlikely to assist in defining flow requirements of riparian vegetation. However, the water dependency of broad vegetation types/complexes identified at each reach can be classified under broad flow regimes (*i.e.* as requiring low frequency, low duration inundation versus high frequency, high duration inundation). This approach is considered by the authors as sufficient to prepare flow linkages for riparian vegetation assemblages/complexes at each site.

Measurements of water quality parameters were made in conjunction with the aquatic fauna sampling. Measurements of temperature (°C), dissolved oxygen (% & mg/L), conductivity (µS/cm) and pH were made *in situ* between the hours of 0900 and 1730 using portable WTW field meters.

Table 6. GPS co-ordinates of replicate sampling sites.

REACH	SUB-CATCHMENT	LOCATION	SITE CODE	GPS (WSG84 ZONE 50) EASTING	NORTHING
1a	Harris River	Upstream end of reach located immediately below Norm's Road bridge, below Harris Dam. Accessed from Harris River Road.	1a-1	420534	6319147
			1a-2	420617	6319123
			1a-3	420631	6319053
			1a-4	420522	6318929
			1a-5	420545	6318857
			1a-6	420655	6318779
1b	Collie River	Upstream end of reach located below Burekup Weir. Accessed from Collie River Road.	1b-1	395519	6312505
			1b-2	395387	6312444
			1b-3	395255	6312277
			1b-4	395138	6312227
			1b-5	394974	6312292
			1b-6	394842	6312346
2	Collie River	Upstream end of reach located immediately below South Western Highway traffic bridge. Upper sites accessed from South Western Highway. Lower sites accessed from the Shine property off Treendale Road.	2-1	389687	6314682
			2-2	389544	6314827
			2-3	389245	6314669
			2-4	389007	6314579
			2-5	388731	6314676
			2-6	388638	6314874
3	Henty Brook	Upstream end of reach located immediately below South Western Highway traffic bridge. Reach extends downstream of the old bridge on Rose Road. Upper sites accessed from South Western Highway. Lower sites accessed from Rose Road.	3-1	388796	6313604
			3-2	388687	6313665
			3-3	388563	6313738
			3-4	388510	6313812
			3-5	388378	6313901
			3-6	388244	6313905

Table 7. Ecological components assessed in the field during November 2008.

VALUE CATEGORY	REACH 1a	REACH 1b	REACH 2	REACH 3
	Harris River	**Collie River**	**Collie River**	**Henty Brook**
Riparian vegetation	Yes	Yes[1]	Yes[1]	Yes
Water Quality	Yes	Yes	Yes	Yes
Macroinvertebrates	Yes	Yes	Yes	Yes
Crayfish	Yes[2]	Not required	Not required	Yes
Fish	Yes[2]	Not required	Not required	Yes
Frogs	Yes	Yes	Yes	Yes
Tortoises	Yes	Yes	Yes	Yes
Waterbirds	Yes	Yes	Yes	Yes
Water Rats	Yes	Yes	Yes	Yes

[1] Not required as part of current scope, but briefly assessed to aid in interpretation of faunal data.

[2] Previously surveyed for the Harris River by Beatty and Morgan (2005) and re-surveyed here for the specific reach.

Macroinvertebrates

At all sites, sampling aimed to maximise the number of macroinvertebrate taxa collected, by sampling as many aquatic habitats as possible over the total 40 - 50 m section of river. This included sampling reed/rush beds, draped vegetation, woody debris, open water column and benthic sediments (cobbles, gravels, sand & silt) in fast and slow flowing habitats. Sampling was conducted with a 250 µm mesh pond net to selectively collect the macroinvertebrate fauna (Plate 3).

Plate 3. Sampling for macroinvertebrates in riffle habitat at site 1B-1 on the Collie River.

Samples were preserved in 70% ethanol and returned to the laboratory for sorting under low power microscope to remove animals. All taxa were identified to the lowest level (species, where possible) and enumerated to log10 scale abundance classes (i.e. 1 = 1 - 10 individuals, 2 = 11 - 100 individuals, 3 = 101-1000 individuals, 4 = >1000). In-house expertise was used to identify invertebrate taxa using available published keys and through reference to the established voucher collections held by WRM. External specialist taxonomic expertise was sub-contracted on an 'as needs be' basis to assist with specific groups. This included Dr Don Edward (UWA) for Chironomidae (non-biting midges) and Dr Mark Harvey (Western Australia Museum) for Acarina (aquatic mites). The existence of rare, restricted or endemic species was determined by cross-referencing taxa lists for each site with the WRM database, the CALM Wildlife Conservation (Specially Protected Fauna) Notice and with the IUCN Red List of Threatened Species.

Fish and Crayfish

A range of sampling techniques was used to collect as comprehensive a list of fish and freshwater crayfish as possible from each reach. Dependent on habitat, techniques included electrofisher, fyke nets, baited box traps, sweep netting, gill nets and visual survey.

Plate 4. Electrofishing in snag habitat along Henty Brook (Reach 3).

Sampling was primarily based around a standard catch per unit effort approach using a Smith-Root Model 12-B battery powered backpack electrofisher (Plate 4). Electrofishing was typically performed in an upstream direction, shocking in all meso-habitats with the intention of recovering as many species as possible. Shocking was not continuous, but targeted areas of optimum habitat, whereby the operator would shock, then move to a new habitat before shocking again, and so prevent fish being driven along in front of the electrical field.

In deeper pools, fyke nets (Plate 5) comprising a single 10 m leader and 5 m net (~8 mm mesh size) were set overnight. Fyke nets were set at a 45° angle to the bank in pools deeper than 1 metre to create a complete barrier to fish passage. A float was placed at the cod-end (closest to the bank) to provide an air space for tortoise. Gill nets (13 mm mesh) were deployed opportunistically in each reach. Mesh box traps (Plate 5) baited with cat biscuits were also set overnight in each reach and cleared the following day. Fish and larger crayfish were identified in the field and released alive. Fish nomenclature follows that of Allen *et al.* (2002).

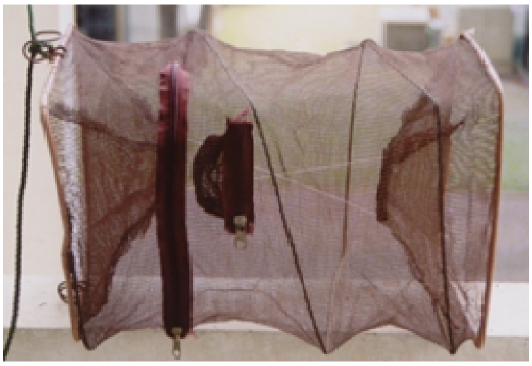

Plate 5. Fyke net (left) and box trap (above).

Frogs

Frog species present at each reach were determined opportunistically by two methods. Initially, by comparing calls heard on the day of sampling with audio files for south-west species (Dale Roberts, Uni of WA, undated). During the breeding season, male frogs make advertisement calls unique to their species to attract mates, allowing positive identifications. Secondly, tadpoles that were collected in macroinvertebrate sweeps were identified to species in the laboratory. Frogs calling at adjacent floodplain wetlands/sumps were also recorded for each site.

The above approaches are not guaranteed to record all species, because a.) frogs do not call at all times, and b.) tadpoles of all species are not always present.

Tortoise

Tortoises are the main water-dependent reptile value likely at each site, and were sampled using fyke nets as for fish fauna. Other reptile species that may inhabit the riparian zone were not surveyed. There is a well accepted relationship between riparian condition and the number and types of reptile species present. However, previous EWR studies have found difficulty in definitively determining the frequency and duration of inundation required by reptile species. This essentially reflects the lack of knowledge of flow requirements of reptile species, which are more dependent on riparian condition for habitat than flows *per se*. Until the specific flow requirements of reptile species are understood, detailed surveys (*i.e.* trapping and pitfalls *etc*) are unlikely to assist in defining flow requirements of reptile fauna. It is more appropriate to detail riparian condition, supported with a literature review to infer reptile fauna condition.

Waterbirds and Water Rats

Opportunistic sightings of waterbirds were also recorded for each site and for adjacent floodplain wetlands/sumplands.

Water rats (*Hydromys chrysogaster*) and their feeding platforms and/or burrows were also noted. Water rats are the main water-dependent mammal known from the Collie River.

RESULTS

Foreshore Condition

Descriptions of foreshore condition are given in Table 8 and photographs of representative foreshore conditions provided in Plates 6-9. Further site photographs are provided in the accompanying CD. All reaches were considered degraded due to flow regulation, historic land clearing and, for most, current pastoral use. Reach 1a downstream from Harris Dam was in better environmental condition than other reaches (*i.e.* B1-A3), the channel was down-cut and heavily sedimented and flows were impeded by abundant emergent and submerged macrophyte growth, including dense beds of the introduced aquatic weed water milfoil (*Myriophyllum aquaticum*), together with native water ribbon (*Triglochin* sp.) and pond weed (*Potomogeton tricarinatus*). Some clumps of introduced water lily (*Nymphaea* sp.) were also present. This reach was similarly given an overall foreshore rating of A3 (slightly disturbed) by WEC and Streamtec (2000). Unlike the current study, however, WEC and Streamtec (2000) found little evidence of erosion. This conclusion may have been based on comparison with prior visual observations by Streamtec (1987-1997) who conducted a number of aquatic fauna surveys before and after construction of the Harris Dam. However no details are given. There is anecdotal evidence that this reach was naturally slower flowing and more silted than the upstream reach between Harris Dam and Norm Road (A.W. Storey, pers. com.). Analysis of long-term changes in erosion and sedimentation post dam construction were beyond the scope of the current study.

The riverine landscape at reaches 1b, 2 and 3 was typical of rural regions throughout the south-west. Channels were characterised by poor bank stability and severe erosion in the form of bank slumping, channel widening, undercutting and (often) extensive sedimentation. Along reaches 1b and 2, pasture grasses (*e.g.* Kikuyu) and weeds, which comprised the understorey vegetation, provided a degree of protection against excessive bank erosion. Flow control barriers (wooden barriers) have been installed along Reach 2 to deflect erosive flows from the steep banks, reduce the energy of high flows and hence reduce rates of active erosion. Of the reaches surveyed, Reach 3 on Henty Brook, west of South Western Highway, was considered in worst condition. The channel was narrow, tightly meandering and deeply incised. Banks were largely devoid of vegetation. In-stream vegetation was virtually absent, with only isolated clumps of submerged macrophytes and emergent sedges. Foreshore condition to the east of South Western Highway was previously assessed by WRM in 2005 (WRM 2006a) and although appreciably degraded, the extent of overall erosion and land clearing was not considered as severe as west of the Highway. Storey (2000) and WEC (2002) also documented foreshore condition east of the Highway, describing it as significantly eroded and ecologically degraded.

Table 8. Results of foreshore condition assessments conducted during the current study.

REACH	SITE CODE	DESCRIPTION	FORESHORE CONDITION	ENVIRONMENTAL RATING
1a	1a-1	Healthy riparian vegetation; moderately dense overstorey of jarrah-marri-blackbutt over open to moderately dense, tall mixed shrubs. Both banks weed infested but with very dense fringing reeds and sedges at level of active channel; very steep banks ±vertical; points of undercutting and bank slumping with large deposits in channel; slow-flowing sluggish channel - shallow pool channels choked with macrophyte; heavily silted (to ~20cm); anoxic muds; abundant organic debris, leaf litter and large woody debris (LWD); poor-moderate soil cohesion.	**B1** – Weed infested: understorey mainly natives	Good
	1a-2	Open to moderately dense overstorey; shallow section choked with emergent macrophytes; heavily sedimented; anoxic muds; poor soil cohesion; major points of undercutting and bank slumping along both left and right banks; open overstorey; very dense fringing sedges; abundance of LWD and leaf litter.	**B1** – Weed infested: understorey mainly natives	Good
	1a-3	Slow-flowing channel similar to 1a-1 but narrowing; abundant submerged and emergent macrophyte; very dense fringing sedges; right hand bank steep; healthy moderately dense overstorey; no erosion evident.; moderate-good soil cohesion	**B1** – Weed infested: understorey mainly natives	Good
	1a-4	Shallow section choked with emergent macrophytes; heavily sedimented; anoxic muds; major points of undercutting and bank slumping along left and right banks;	**A3** – Slightly disturbed: local weed infestations	Good

REACH	SITE CODE	DESCRIPTION	FORESHORE CONDITION	ENVIRONMENTAL RATING
		open overstorey; dense fringing sedges; abundance of LWD and leaf litter.		
	1a-5	Very narrow, shallow section of river (10-15 cm deep) upstream of pool; otherwise similar to 1A-2; abundance of LWD and leaf litter; good soil cohesion; no evidence of erosion.	**A3** – Slightly disturbed: local weed infestations	Good
	1a-6	Deep pool; open jarrah overstorey over moderately dense to dense, tall mixed shrub layers; dense fringing sedges and abundant emergent and submerged macrophyte; abundance of LWD and leaf litter; bedrock and boulders along left bank but otherwise poor soil cohesion; channel heavily sedimented (~20 cm); anoxic muds.	**A3** – Slightly disturbed: local weed infestations	Good
1b	1b-1	Riffle zone in farmland; open overstorey of flooded gum and peppermint over tea tree; understorey all pasture species and Watsonia; some sedges/rushes present in the rock/riffle section; no macrophytes; no overhanging vegetation; large, deep pool downstream; stock access limited by fencing; good soil cohesion due to grass cover but evidence of channel widening and bank slumping and down-cutting along left and right banks; no macrophytes or algae; turbid water. Active channel banks of low-moderate steepness; flood-level banks steep ±vertical and to 3-4 m high. Freshwater sponge present.	**C1**– Erosion prone: understorey weeds only	Poor
	1b-2	Riffle zone similar to 1b-2. Freshwater sponge present.	**C1**– Erosion prone: understorey weeds only	Poor
	1b-3	Sandy riffle area; riparian vegetation and bank condition similar to 1b-1; some LWD.	**C1**– Erosion prone: understorey weeds only	Poor
	1b-4	Shallow, broad sandy channel; open overstorey of flooded gum and peppermint over pasture grasses and weeds; very steep banks; erosion prone – major undercutting and bank slumping along left and right banks; heavily silted (~ 40 cm) along edges; poor soil cohesion; stock access limited by fencing; turbid water.	**C1**– Erosion prone: understorey weeds only	Poor
	1b-5	Similar to 1b-4, but with large mobile slugs of sand in channel bed.	**C1** – Erosion prone: understorey weeds only	Poor
	1b-6	Small rapid area and waterfall at confluence of small tributary; open canopy of flooded gum over grasses and blackberry; abundant LWD; left and right banks very steep ±7 m high in places; erosion prone – major undercutting; bank slumping; channel upstream heavily sedimented with sand; stock access limited by fencing.	**C1** – Erosion prone: understorey weeds only	Poor
2	2-1	Farmland. Sparse to open overstorey of flooded gum over scattered tea tree, pasture grasses and weeds – dense *Watsonia*. Dense stand of flooded gum recruits on left hand bank. Broad meandering channel with large mobile sand deposits (slugs) and sand banks; turbid tannin-stained waters; moderately deep channel pools; both banks erosion-prone - down-cut, erosion-prone; bank slumping; channel widening. Active channel banks of low-moderate steepness; flood-level banks steep ±vertical and ~4 m high; stock access limited by fencing.	**C1** – Erosion prone: understorey weeds only	Poor
	2-2	As for 2-1. Site has flow control barriers (wooden barriers) to help reduce bank erosion.	**C1 / C2** – Eroding: soil exposed; understorey weeds only	Very Poor
	2-3	As for 2-1.	**C2 / C3** – Erosion and subsidence; soil exposed; understorey weeds only	Very Poor
	2-4	As for 2-1. Some LWD and macrophyte beds (*Vallisneria*, *Potamogeton*)	**C2 / C3** – Erosion and subsidence; soil exposed; understorey weeds only	Very Poor

REACH	SITE CODE	DESCRIPTION	FORESHORE CONDITION	ENVIRONMENTAL RATING
	2-5	As for 2-1. Some LWD and macrophyte beds.	**C2 / C3** – Erosion and subsidence; soil exposed; understorey weeds only	Very Poor
	2-6	As for 2-1.	**C2 / C3** – Erosion and subsidence; soil exposed; understorey weeds only	Very Poor
3	3-1	Farmland. Narrow meandering channel; sparse overstorey of flooded gum; understorey all pasture grasses and weeds; dense Watsonia, blackberry and some willows. Grasses encroaching on channel; a few emergent and submerged macrophytes; both banks and bed erosion prone; heavily sedimented; steep (± vertical) down-cut bank on left hand side ~ 3 m; exposed soil. Turbid, tannin-stained waters.	**C3** – Erosion and subsidence	Very Poor
	3-2	Scattered to open flooded gum and peppermints over pasture species and weeds; abundant LWD and leaf litter; both banks very steep, heavily eroded, down-cut and slumped, lot of exposed tree roots. Bed eroded down to bedrock. Logs and tree debris constricting flow. Turbid, tannin-stained waters; poor soil cohesion. Hay fields along either bank.	**C3** – Erosion and subsidence	Very Poor
	3-3	As for 3-2; livestock paddocks along either bank.	**C3** – Erosion and subsidence	Very Poor
	3-4	Deeply incised channel with frequent meanders through farmland. Cattle access. Open to moderately dense overstorey of flooded gum; understorey all pasture grasses and weeds; isolated clumps of native rush; both banks heavily down-cut; bank slumping/ subsidence; channel widening and deepening; some LWD in-stream. Very turbid, tannin-stained waters.	**C3 / D1** – Erosion and subsidence	Very Poor
	3-5	As for 3-4	**C3 / D1** – Erosion and subsidence	Very Poor
	3-6	As for 3-4	**C3 / D1** – Erosion and subsidence	Very Poor

Site 1a-2: dense beds of introduced water milfoil and native water ribbon in main channel together some introduced water lily (B1)

Site 1a-6: introduced water milfoil (foreground) and fringing sedges (sword sedge & twig-rush) (A3)

Site 1a-4: boulders lining active channel (A3)

Site 1a-4: deep pool in main channel (A3)

Plate 6. Reach 1a on the Harris River, downstream from Norm Road bridge.

Site 1b-2: riffle zone below shallow, sedimented pool; degraded riparian vegetation

Site 1b-3: open flooded gum woodland with understorey of peppermints and tea-tree over pasture grasses

Site 1a-5: mobile sand slug in pool on main channel

Site 1b-6: small cascade on main channel; slumped bank and undercut tree roots visible in background

Plate 7. Reach 1b on the Collie River, below Burekup weir.

Site 2-1: small riffle on main channel; degraded understorey vegetation dominated by pasture species and *Watsonia* (background); sediment slug in foreground that has been stabilised by grasses.

Site 2-2: wooden barrier to deflect high flows and reduce bank erosion along main channel

Site 2-6: some large woody debris ± parallel to flow; mobile sand deposit on inner meander bend

Site 2-4: colonising grass on sand deposits (left) and steep banks largely cleared of native vegetation(background)

Plate 8. Reach 2 along the Collie River, immediately west of South Western Highway.

Site 3-1: main channel beside hay field largely devoid of native vegetation

Site 3-2: woody debris from trees and shrubs partially blocking main channel; steep eroded banks and exposed bedrock (left)

Site 3-4: small riffle encroached by grasses

Site 3-6: eroded banks and exposed soil

Plate 9. Reach 3 along Henty Brook, immediately west of South Western Highway.

Water Quality

Most water quality values were within the current recommended range for the protection of south-west aquatic ecosystems (ANZECC/ARMCANZ 2000). The exceptions were salinity in all reaches and dissolved oxygen (DO) in Reach 1a (Table 9). Salinity at all sites exceeded recommended guideline trigger values of 120 µS/cm (ca. 80 mg/L TDS) for upland rivers and 300 µS/cm (204 mg/L TDS) for lowland rivers. The salinity at study sites ranged from 432 - 568 µS/cm in Reach 1a, 856 - 923 µS/cm in Reach 1b, 138 - 1557 µS/cm in Reach 2, to 1205 - 1308 µS/cm in Reach 3. DO in Reach 1a had a range of 67 - 77% and was considered low for an upland river. Flow in this reach was 'sluggish' with channel pools chocked by aquatic macrophyte and deep organic silts and debris over a sub-layer of anoxic mud. Turbidity was not measured, but all sites (including upland sites along Reach 1a) appeared visually turbid and tannin-stained.

Table 9. Water quality in November 2008.
NR = not recorded (equipment failure).

REACH	SITE CODE	DATE	TIME	PH	TEMP	EC µS/cm	DO %	DO mg/L	REDOX mV
1a	1a-1	3/11/08	12:30	6.83	15.1	505	69	6.9	-8.7
	1a-2	4/11/08	09:30	7.08	14.0	568	70	6.8	-21.4
	1a-3	3/11/08	13:20	6.55	15.3	517	70	7.3	42.9
	1a-4	3/11/08	16:20	6.84	15.5	432	77	7.6	9.1
	1a-5	3/11/08	14:30	6.88	15.3	529	72	7.0	-9.3
	1a-6	3/11/08	15:20	6.67	15.3	530	67	6.7	0.8
1b	1b-1	4/11/08	12:30	6.95	17.9	856	93	9.1	-13.6
	1b-2	4/11/08	13:10	7.14	18.1	923	94	9.0	-26.5
	1b-3	4/11/08	14:00	7.20	18.2	911	98	9.5	-26.2
	1b-4	4/11/08	15:40	7.27	18.9	907	104	9.8	-31.8
	1b-5	4/11/08	16:15	6.39	18.9	901	93	9.0	27.9
	1b-6	4/11/08	17:00	7.06	19.1	890	102	9.7	-20.8
2	2-1	5/11/08	09:50	6.75	18.2	1038	86	8.2	-8.0
	2-2	5/11/08	10:30	6.53	18.3	1308	91	8.8	6.3
	2-3	5/11/08	11:15	6.79	18.3	1447	65	6.8	-5.4
	2-4	5/11/08	12:40	6.78	18.1	1514	91	8.6	-6.9
	2-5	5/11/08	13:20	6.82	18.4	1316	87	8.3	-2.8
	2-6	5/11/08	14:30	6.60	18.2	1557	82	8.1	-15.5
3	3-1	6/11/08	09:10	7.04	14.5	1261	75	7.2	NR
	3-2	6/11/08	10:35	7.17	14.6	1272	64	6.5	NR
	3-3	6/11/08	11:10	7.33	14.3	1308	74	7.6	NR
	3-4	6/11/08	12:00	7.26	14.1	1323	73	7.6	-31.5
	3-5	6/11/08	12:40	6.81	14.1	1292	81	8.4	NR
	3-6	6/11/08	13:20	7.42	13.8	1205	74	7.7	-38.7

Macroinvertebrates

Taxonomic Composition and Richness

A systematic list of microinvertebrate fauna recorded is provided in Appendix 1. A total of 129 taxa ('species') were collected together with another 23 specimens that could not be positively identified owing to immaturity of life stage or sex (males of a species are often required for positive identification). A summary of the types of taxa collected is given in Table 10.

The macroinvertebrate fauna was dominated by Insecta (85-89%). Of these, Diptera (two-winged flies), and in particular Chironomidae (non-biting midge), were the most common, followed by Coleoptera (aquatic beetles). Mollusca and Crustacea comprised less than 10% of the total fauna in each reach.

Table 10. Summary of macroinvertebrate fauna recorded during the current study.

MACROINVERTEBRATES	SPECIES PER REACH			
	1a	1b	2	3
Porifera (freshwater sponges)	--	1	--	--
Mollusca				
Bivalvia (mussels)	--	2	2	2
Gastropoda (snails)	--	1	2	3
Crustacea				
Palaemonidae (shrimps)	1	1	1	1
Parastacidae(crayfish)	2	1	2	1
Perthidae (amphipods)	2	1	1	2
Micro-crustacea (ostracods, copepods *etc*)	3+	3+	3+	3+
Arachnida				
Acarina (water mites)	1	3+	3+	1
Insecta				
Ephemeroptera (mayflies)	3	4	4	4
Plecoptera (stoneflies)	1	1	1	1
Trichoptera (caddis-flies)	8	9	8	9
Odonata (dragonflies & damselflies)	4	4	2	7
Hemiptera (true bugs)	2	1	5	3
Coleoptera (aquatic beetles)	9	7	20	18
Diptera (two-winged flies)	34	31	29	28
Total number of species per reach	***69***	***68***	***79***	***85***
Average number of species per site	***32***	***32***	***33***	***37***

Of the total 129 species identified, ca. 30% were recorded from single reaches only and of these, ca. 20% were collected from single sites. Species collected from single sites are generally referred to as 'singletons' and can contribute greatly to spatial (and temporal) variation in community assemblages. Taxa richness at individual sites averaged between 32 and 37, with total richness for each reach ranging from 68 species in Reach 1b below Burekup weir to 86 species in Reach 3 on Henty Brook (Table 10). The more heavily impacted reaches (2 & 3) had the highest total richness. This phenomenon has been recorded in other surveys of rivers on the Swan Coastal Plain and elsewhere, where low to moderate nutrient enrichment is believed to contribute to higher species richness and diversity (Creagh *et al.* 2003, Gray 2004).

Several snail, dragonfly and aquatic beetle and bug species were only recorded from the most degraded reach, Reach 3. Snail species included *Austropeplea lessoni* and two introduced snails *Pseudocuccinea collumella* and *Physa acuta*. Dragonflies included *Orthetrum caledonicum*, *Diplacodes haematodes* and beetles and bugs included *Necterosoma penicillatus*, *Sternopriscus browni, Platynectes* sp., *Rhantus* sp., *and Anisops* sp. All these species have a preference for slower flowing rivers, backwaters and wetlands. Conversely, species recorded only from forested Reach 1a below Harris Dam were the beetle *Sternopriscus marginatus* and the caddis-fly *Condocerus aptus*.

Approximately 15% of total species collected were common to all four reaches. Common species were gilgies, freshwater shrimps, two mayflies (*Tasmanocoenis tillyardi*, *Cloeon* sp.), one beetle (*Paracymus pygmaeus*) and two caddis flies (*Cheumatopsyche* sp. AV2, *Trianodes* sp.) (Appendix 1). There were also a number of common and abundant midge species (Chironomidae), including *Chironomus* aff. *alternans*, *Cladopelma curtivala*, *Cricotopus annnuliventris*, *Paramerina levidensis* and *Procladius paludicola*.

Conservation Significance

South-West Endemics

A conservation category was assigned to each of the taxa based on level of endemicity and rarity (Figure 2). Owing to taxonomic uncertainties, the conservation status of a great many taxa could not be determined and the endemicity of ca. 50% of the taxa remains unknown. There is a paucity of research on macroinvertebrates of Australia, and Western Australia in particular, and the extent of distributions within the southwest have not been adequately surveyed. The lack of relevant published taxonomic keys for many species is also problematic. The percentage of south-west endemics (or likely endemics) in each reach ranged from 24% in Reach 2 to 32% in Reach 1b (Figure 2).

South-west endemics (or likely endemics) collected during the current study included 10 caddis-fly species (Hydrobiosidae, Hydropsychidae, Hydroptilidae & Leptoceridae), 4 aquatic beetles (Dytiscidae), 3 species of mayfly (Baetidae & Leptophlebiidae), 3 midges (Chironomidae), 3 dragonflies (Gomphidae, Oxygastridae, Synthemistidae), the damselfly *Austroaeschna anacantha*, the stonefly *Newmanoperla exigua*, the small freshwater cockle *Musculium kendricki* and the freshwater limpet *Ferrissia petterdi*.

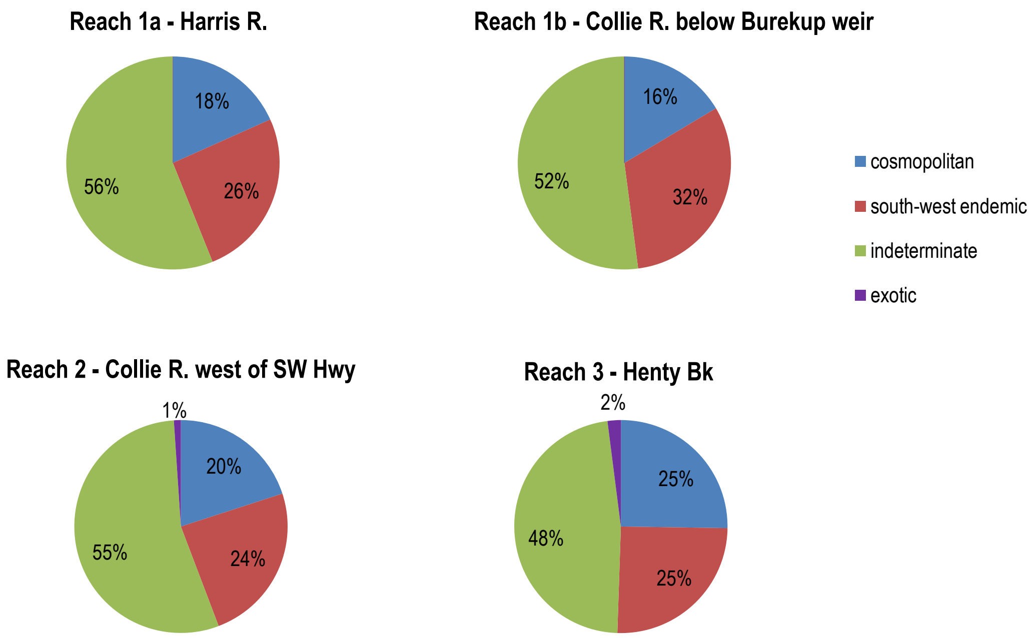

Figure 2. Percentage of endemic macroinvertebrate species. Legend: 'cosmopolitan' refers to species that have a broader state distribution and/or occur Australia-wide or world-wide; 'south-west endemic' includes species likely to be endemics but which require further research; 'indeterminate' refers to taxonomic uncertainties or species whose state-wide distributions are unknown; 'exotic' refers to introduced species.

Rare and/or Restricted Taxa

Only one species was considered to have a restricted distribution within the south-west. This was the freshwater mussel *Westralunio carteri*, which was common and abundant in reaches 1B, 2 and 3. The mussel is currently listed as a Priority 4 species under the Department of Environment and Conservation (DEC) *Wildlife Conservation (Specially Protected Fauna) Notice 2008* and as 'vulnerable' under the IUCN Red List of Threatened Species (2008). DEC Priority 4 species are those not currently threatened, but with fragmented and/or potentially vulnerable populations in need of monitoring. Though *Westralunio carteri* may be locally common in some areas, many populations are believed to be in decline due to secondary salinisation and heavy siltation (WRM 2005a).

The hydropsychid caddis-fly *Smicrophylax australis,* which was only present in Reach 1a and 1b, is often reported in the literature as having a limited south-west distribution, known only from fragmented populations. However, Bunn *et al.* (1986), Bunn (1988) and Dean and Bunn (1989) report it as one of the most abundant and widespread caddis-flies in small perennial streams of the northern jarrah forest. This disparity may be due to a lack of detailed surveys of such smaller streams in recent years (ARL 2006).

Gondwanic Fauna

There were also a number of other endemics notable for their Godwanic[3] affinities. These included the gripopterygid stonefly *Newmanoperla exigua* (reaches 1a, 1b & 3), the telephlebiid damselfly *Austroaeschna anacantha* (reaches 1a & 1b) and four dragonflies; the synthemistid *Austrosynthemis cyanitincta* (reaches 1a, 1b & 3), the oxygastrid *Hesperocordulia berthoudi* (reaches 1a & 3) and the gomphid *Austrogomphus collaris* (reaches 1b, 2 & 3).

In south-western Australia, Gondwanic (or relict) species are believed to be particularly at risk because they have specialised requirements and habitats that are usually topographically restricted and vulnerable to disturbance and fragmentation (York Main 1996). While the above species are regularly encountered at range of waterbodies throughout the south-west, there are no published data and (likely) little current research into population dynamics and long term changes in population sizes and distributions.

Introduced Species

Two introduced (exotic) snail species were also recorded; the American ribbed fluke snail *Pseudosuccinea collumella* (reaches 2 & 3) and *Physa acuta* (Reach 3). Both snails are widespread throughout wetlands and river systems in other parts of the south-west. They are typically found in slow moving freshwater streams, ponds and dams. *P. columella* is an intermediate host for liver fluke *Fasciola hepatica*, a parasite that infests the liver and bile ducts of sheep, cattle and horses. Humans can also be infected by ingesting contaminated plant or animal material.

EPT Taxa

A greater diversity and abundance of caddis-flies mayflies (Ephemeroptera), Plecoptera (stoneflies) and caddis-flies (Trichoptera), or EPT taxa, together with dragonflies and damselflies is usually taken as indicative of good water quality and overall better stream health. Disturbed and degraded rivers typically have fewer EPT taxa than pristine rivers. The number of EPT taxa is often used as a metric for biomonitoring assessments of river health (Marchant *et al.* 1995, Marshall *et al.* 2001). Trend analysis has also shown EPT taxa richness to have an advantage over total taxa richness for monitoring ecosystem change, as EPT is typically "more stable and hence more predictable" (Lenat & Penrose 1996).

The number of EPT species was calculated for each of the current reaches and is shown in Table 11. Counter to expectations, Reach 3 supported a greater EPT taxa richness than Reach 1a. However, overall, differences in EPT taxa richness between reaches were slight. This may reflect disturbed habitat conditions in all four reaches. Ideally, the number of EPT taxa present should be determined over a number of seasons to account for natural seasonal and annual variation in community assemblages.

The total number of EPT taxa for a site/location may be calculated at family, genus or species-level. Species-level resolution potentially provides enhanced ability to detect change, but it also tends to be more variable, *i.e.* 'noisy', in comparison with family or genus-level richness. The criticism of family-level identification (which is often used for rapid bioassessment programs) is that not all species within these families are equally sensitive to water pollution. A few EPT taxa at least are known to be extremely tolerant (*e.g. Tasmanocoenis tillyardi*) and there is a paucity of information on the sensitivity of south-west endemics.

[3] Gondwanic: relict species from the southern super-continent Gondwana that existed approximately 144 to 195 mya and included what is now Australia, Africa, Antarctica, South America, India, New Zealand and Madagascar.

Table 11. Presence-absence of EPT taxa (species-level) in each reach, where '1' = present and '--' = absent.

			REACH			
ORDER	**FAMILY**	**SPECIES**	**1a**	**1b**	**2**	**3**
Ephemeroptera	**Caenidae**	*Tasmanocoenis tillyardi*	1	1	1	1
	Baetidae	*Cloeon* sp.	1	1	1	1
		Baetidae Genus 1.	--	1	1	1
	Leptophlebiidae	*Atalophlebia* ?sp. AV17	--	1	1	1
Plecoptera	**Gripopterygidae**	*Newmanoperla exigua*	1	1	--	1
Trichoptera	**Ecnomidae**	*Ecnomus* sp.	1	1	1	1
	Hydrobiosidae	*Taschorema pallescens*	--	1	--	--
	Hydropsychidae	*Cheumatopsyche* sp. AV2	1	1	1	1
		Smicrophylax australis	1	1	--	--
	Hydroptilidae	*Acritoptila* sp.	1	1	1	1
	Leptoceridae	*Oecetis* sp.	1	1	1	1
		Condocerus aptus	1	--	--	--
		Notoperata tenax	1	1	--	1
		Notalina spira	--		1	1
		Notalina sp. AV16	--		1	1
		Trianodes sp.	1	1	1	1
	Philopotamidae	*Hydrobiosella* sp.	--	1	--	--
		Total number of EPT species	***11***	***14***	***11***	***13***

Functional Feeding Groups

Macroinvertebrates were categorised on the basis of their feeding behaviour, *i.e.* functional feeding group. Some feeding groups, such as specialised shredders and scrapers tend to be more sensitive to environmental degradation than more generalist feeders such as collectors and filterers. This provides a trophic metric which can be used to evaluate community response to anthropogenic disturbance. The functional complexity and 'health' of a river system is influenced by the diversity of functional feeding groups (Cummins 1974, Cummins & Klugg 1979). In most instances however, caution should be applied when using this metric as accurate autecological information is not available for many south-west taxa. For the current study, functional feeding groups were assigned to each species for which information could be gleaned from the literature. Sources included Williams (1980), Bunn (1985, 1986, 1988), Barnes (1987), Cartwright (1997), St Clair (2000), Gooderham & Tsyrlin (2002) and the database established by WRM. The percentages of each functional feeding group from all four reaches are presented in Figure 3.

Current theories of functional organisation of streams of the south-west (see Bunn 1985, 1986, 1988) predict relatively undisturbed, forested streams will be dominated by collectors and predators, but with a high proportion of shredders. While all reaches surveyed in the current study were dominated by collectors and predators, shredders represented only 10% of community assemblages, even in forested Reach 1a below the Harris Dam (Figure 3). Shredders would be expected to decrease if the input of coarse particulate material from riparian vegetation decreased or was smothered by high sediment loads. Similarly, filterers may decrease if total suspended solid (TSS) concentrations become too high and limit their capacity to filter food from the water. The percentage of filterers was indeed much less in lowland reaches 2 and 3. On the other hand, an increase in grazers might be expected in waterbodies where algal production is high due to nutrient enrichment and/or a more open vegetation canopy resulting in increased light and higher water temperatures. Temporal changes in proportions of functional feeding groups will also occur with natural seasonal changes in invertebrate community structure.

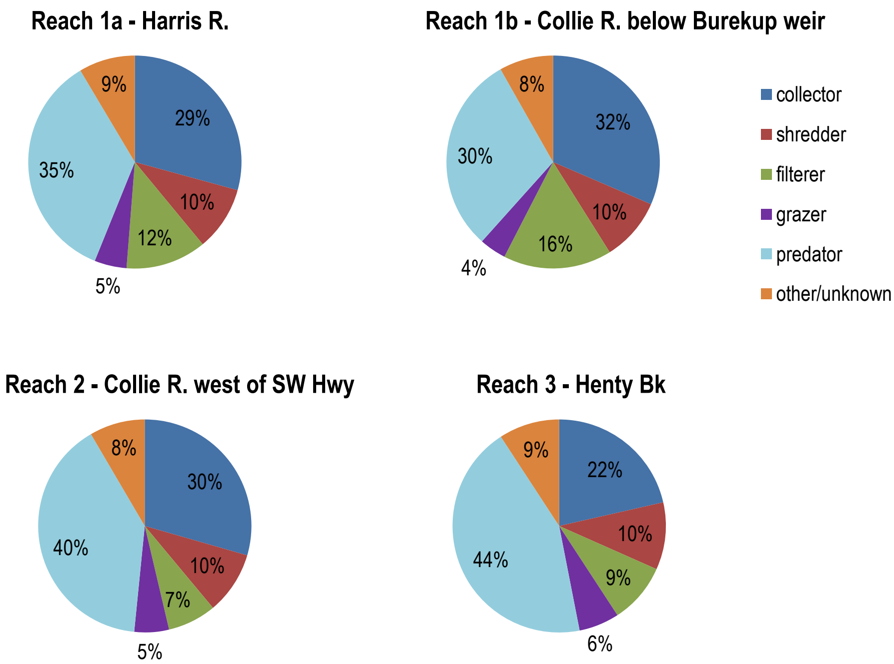

Figure 3. Percentage of functional feeding groups within macroinvertebrate assemblages of sampled reaches. Functional feeding groups: 'shredders' feed on coarse particulate matter (CPOM > 1mm); 'collector's feed on fine particulate matter (FPOM < 1mm); 'filterers' filter suspended particles from the water column and are often viewed as a subset of collectors; 'grazers' are those animals that graze or scrape algae and diatoms attached to the substrate; 'predators' capture live prey.

Comparisons with Other Studies

Comparisons with historic data for the Upper and Lower Collie (refer 'Literature Review' section, above) were made by standardising taxonomy between studies (Figure 4). Invertebrate assemblages were similar to those recorded in the current study, with an abundance and diversity of Insecta, particularly Diptera. However, species richness at current sites was generally lower. The exceptions were average species richness recorded by Streamtec (1997) for the Harris River (20 species) and total species richness recorded by WRM (2007) for a highly saline site in the upper East Branch of the Collie River (14 species). The data of Streamtec (1997) should not be viewed as directly comparable due to differences in sampling methodology (Surber sampling *vs* broad sweep sampling). Nor do Streamtec (1997) provide data on total richness at individual sites in the Harris River, *i.e.* forested sites versus farmland sites. In general however, Streamtec (1997) recorded a greater diversity of ephemeropteran and plecopteran species than were recorded for the current reaches or for other previously surveyed parts of the Collie system, i.*e.* the East Branch, Bingham River and Boronia Gully (WRM 2007, 2009). The current study did record a greater diversity of trichopteran species than in the East Branch, Bingham River or Boronia Gully. Other notable differences were the higher percentage of predators (≥ 50%) in the East Branch and Bingham River. The percentage of predators has been suggested as one of the more useful metrics for predicting disturbance (Rawer-Jost 2000) - the percentage increasing as the level of disturbance increases.

With respect to comparisons with other nearby rural river systems, WRM (2008) recorded similar macronvertebrate assemblages in the Brunswick River, with an abundance and diversity of Insecta, particularly Diptera. An average species richness of 44 was reported from two sites sampled in November 2007 (Figure 4). The number of EPT taxa and percentgaes of predators and collectors was most similar to that recorded in current reaches 2 and 3.

Creagh *et al.* (2003) assessed the biodiversity of aquatic invertebrates in the Harvey River system in November 2003. They also recorded a similar macroinvertebrate fauna with a predominance of predators and collectors and a high proportion of coleopterans and dipterans. Taxa richness at forested upland sites ranged from 37 in McKnoe Brook through to 40 in Samson Brook and 44 in Harvey River below Stirling Dam (Figure 4).

A wide range in total taxa richness was reported for open farmland sites, ranging from less than 20 in the lower Harvey River (Sunnyvale Farm) and lower Sampson Brook, to around 44 in Wokalup and Wellesley brooks (Creagh *et al.* 2003).

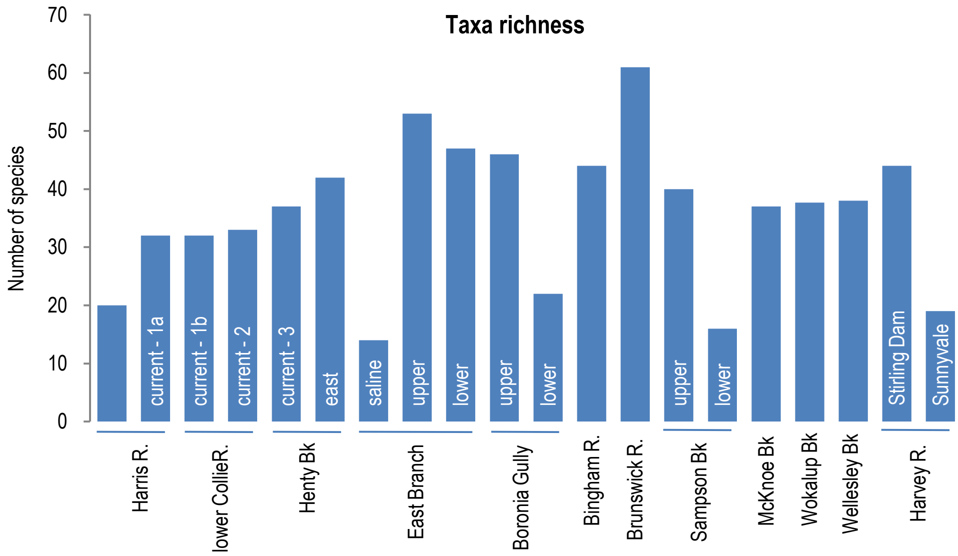

Figure 4. Comparison of species richness per site. The average site richness is shown for current reaches 1a, 1b, 2 and 3 and for historic data from the Harris River (Streamtec 1997), Henty Brook east (WRM 2006a), Brunswick River (WRM 2008, spring data) and Sampson Brook in the Harvey River catchment (source Creagh *et al.* 2003). Other data are total taxa richness per site for the Collie East Branch and Bingham rivers (WRM 2007), Boronia Gully (WRM 2009), Sampson, Mcknoe and Wellesley brooks and the Harvey River (Creagh *et al.* 2003). Note Streamtec (1997) data is quantitative Surber data collected seasonally over a number of years. Taxonomy has been standardised between studies.

Fish and Crayfish

A total of four native fish species, two exotic fish species and two native freshwater crayfish were recorded (Table 12). The most common and abundant native fishes were the western minnow (*Galaxias occidentalis*) and the western pygmy perch (*Edelia vittata*). The two other native fish species, nightfish (*Bostockia porosa*) and freshwater cobbler (*Tandanus bostocki*), were only recorded in Reach 3; catfish were represented by a single juvenile (0^+) in poor condition. Native freshwater crayfish included gilgies in Reach 1a and marron in Reach 1a and Reach 2. The only exotics recorded were a single trout (?*Oncorhynchus mykiss*) in Reach 1b and abundant mosquitofish (*Gambusia holbrooki*) in Reach 2.

Table 12. Fish and crayfish recorded during the current study in November 2008, together with additional records from past studies (refer Table 3 for sources).

Codes: ★ present, ★★common or ★★★abundant during current study; ✓additional historic record; † exotic species

REACH	FISH								CRAYFISH	
	WESTERN MINNOW	WESTERN PYGMY PERCH	NIGHTFISH	COBBLER	SWAN RIVER GOBY	TROUT†	REDFIN PERCH†	*GAMBUSIA*†	GILGIE	MARRON
1a	★★★	★★★	✓				✓	✓	★★★	★
1b	★	★★★	✓	✓	✓	★	✓	✓		
2	✓	✓	✓	✓	✓		✓	★★★		★
3	★★★	★★★	★	★						

Based on the limited literature on the Harris River, lower Collie River and Henty Brook, it is assumed that the fish fauna as sampled in November is representative. The additional species of catfish and Swan River goby are also likely to inhabit reaches 1b and 2 (WRM 2003). Landowners have commented that cobbler breed in the pools in Reach 1b in December. The fact that fish are highly mobile means they may not necessarily be present at a specific location on the date sampled. Their absence should not be taken to imply they no longer inhabit the reaches. A more intensive dedicated survey may be necessary to establish the current population size of cobbler in reaches 1b and 2. WRM (2003) captured a total five specimens of cobbler from these reaches in March 2003. In terms of catch per unit effort this was considered a relatively high number to be taken by electrofishing as cobbbler generally prefer deeper water which is difficult to wade (WRM 2003).

Of note were the absence of nightfish from Reach 1a in the Harris River. Beatty and Morgan (2005) previously commented that populations of nightfish downstream of Harris Dam may be un-sustainable. They also noted relatively low abundance and low level of recruitment in western minnows downstream of the dam. A total of 7 western minnows were captured during the current study with standard lengths of 24, 25, 59, 62, 63, 71, 76 mm, representing at least two age classes; likely 0^+ and 1^+. This was considered to represent a moderately high number, given the survey techniques employed and the habitat conditions – deep turbid pools coupled with weed-choked shallows. A number of other individuals were also oserved but not captured. While recorded lengths suggested recruitment was still occurring, the extent and success of recruitment could not be ascertained within the scope of the current study.

Storey (2003) documented low abundance of pygmy perch between Burekup weir and the Australind bypass. While the current study recorded a relatively high abundance of pygmy perch (30) in Reach 1b, immediately below Burekup weir, no specimens were recorded in the downstream Reach 2, west of South Western Highway. This would appear to substantiate concerns raised by Storey (2003) as to the viability of this species in lower reaches of the Collie River. Sizes recorded in November 2008 ranged from 10 mm to 50 mm SL, likely representing two age classes; 0^+ and 1^+.

Numbers of crayfish were also unexpectedly low in all but Reach 1a. A similar finding was reported by Storey (2003) for the lower Collie River between Burekup weir and the Australind bypass. Reasons for the low numbers are unknwn. It may reflect poor water quality, poor habitat condition and/or substrate composition. Storey (2003) postulated introduced redfin perch and trout could be the cause as they are known to predate heavily on both native crayfish and native fish (Morgan *et al.* 2002).

Frogs

Opportunistic surveys for frogs recorded three species present at all four reaches; Glauert's froglets, quacking froglets and slender tree frogs (Table 13). The presence of all three species was based on calls heard on the day of survey. Tadpoles of Glauert's froglet and the slender tree frog have previously been collected from Henty Brook, east of South Western Highway. A fourth species, the squelching froglet *Crinia insignifera*, is also known to breed in Henty Brook (WRM 2006a) and in the Bingham River (WRM 2007) but was not recorded during the current survey. None of these species is considered rare or restricted in distribution.

Table 13. Frogs recorded during the current study.

SPECIES	REACH
Glauert's froglet *Crinia glauerti*	1a, 1b, 2, 3
Quacking froglet *Crinia georgiana*	1a, 1b, 2, 3
Slender tree frog *Litoria adelaidensis*	1b, 1b, 2, 3

Based on the literature review, at least three other species are likely to occur in the riparian zones of all four reaches; Lea's frog *Geocrinia leai*, Gunther's toadlet *Pseudophryne guentheri* and the western green tree frog *Litoria moorei* (Dames & Moore 1983, Bamford & Watkins 1983).

Tortoise

No tortoises were recorded during the current study. The long-necked tortoise *Chelodina oblonga*, has been recorded from the Collie River East Branch (WRM 2007) and local landowners report it as widely occurring throughout the Upper and Lower Collie.

Waterbirds

Opportunistic surveys recorded only five waterbird species from Reach 2 (Table 14). All species recorded are common and none are listed under JAMBA, CAMBA or CMS treaties. The narrow river channel and lack of a large, open water bodies means the surveyed reaches are unlikely to support an abundance of waterbirds nor provide important waterbird habitat. Loss of fringing vegetation has also reduced suitable nesting sites across much of the floodplain. Typically, waterbird use tends to be highest in large permanent wetlands with high diversity and abundance of vegetation (Broom & Jarman 1983, Halse *et al.* 1993, Storey *et al.* 1993).

Table 14. Waterbirds recorded during the current study.

SPECIES	REACH
Australian white ibis *Threskiornis molucca*	2
Shelduck *Tadorna tadornoides*	2
Wood duck *Chenonetta jubata*	2
Pacific black duck *Anas superciliosa*	2
Yellow-billed spoonbill *Platalea flavipes*	2

Water Rats

A water rat burrow and feeding platforms were observed along Reach 1B below Burekup weir, but no animals were observed. Water rats have been documented as occurring along the East Branch at Coolangatta (WRM 2007) and in permanent pools of the South Branch (WEC & Streamtec 2001).

CONCLUSIONS

EXISTING ECOLOGICAL VALUES

The present condition of the reaches has been determined from literature review and field survey. Based on this, the current condition ranged from fair-good at Reach 1a (Harris River) through to poor in reaches 1b and 2 (lower Collie below Burekup weir and west of the Highway) and very poor at Reach 3 (Henty Brook west of the Highway). While Reach 1a retains much of its native riparian vegetation, the riparian zone in reaches 1b, 2 and 3 has changed from what would have been a dense under- and overstorey of native vegetation pre-European settlement, to a degraded system, with reduced plant diversity and invasions by weed species. The flows have no doubt been dramatically altered. Initially the system was likely seasonal. It may then have become permanently flowing due to logging and clearing. Impoundment then would have reduced discharge, and flows would have become irregular, with high summer flows as a result of releases to irrigators and lower winter flows due to impoundment.

Channel morphology has been altered in reaches 1b, 2 and 3 and a deep channel now carries flows which would once have flooded the flats on the coastal plain. The channels are incised due to increased flows resultant of catchment clearing and there is erosion of the channel in the foothills (*e.g.* Reach 1b) and coastal plain (reaches 2 and 3). Flow control barriers (wooden barriers) have been installed along Reach 2 to deflect erosive flows from the steep banks, reduce the energy of high flows and hence reduce rates of active erosion. In Reach1a below Harris Dam, channel pools are heavily silted and dense macrophyte growth obstructs shallower sections. Salinity is elevated in all reaches. Numbers of sensitive macroinvertebrate taxa (*e.g.* mayflies & stoneflies) appear to have been reduced, even in forested Reach 1a. In general, macroinvertebrate assemblages are dominated by predators and collectors with a paucity of shredders. With respect to fish and crayfish species, nightfish are notably absent from Reach 1a in the Harris River and there are few pygmy perch in the lower Collie River west of South Western Highway. Numbers of crayfish are low in all but Reach 1a, while introduced mosquitofish and redfin perch are widespread in all but Reach 3 on Henty Brook. Rainbow trout are also present in Reach 1b below Burekup weir.

Although surveyed reaches were considered ecologically degraded to a lesser or greater extent, they all continue to support a moderate diversity of aquatic macroinvertebrates, including a few Gondwanic species, as well as fish and crayfish. All these fauna have ecological value. Reaches 1b, 2 and 3 support populations of the Priority 4 freshwater mussel, *Westralunio carteri*. Reaches 1a and 1b support the hydropsychid caddis-fly *Smicrophylax australis*, which is thought to have a limited distribution in the south-west. Another Priority 4 species, the water rat, also occurs along Reach 1b, and though not recorded during the current study, there is anecdotal evidence that cobbler still breed in the pools in Reach 1b. A relatively high number of cobbler were recorded WRM (2003) from this reach and Reach 2 in March 2003.

FLOW REQUIREMENTS

Returning the river system to pre-European state or even to pre-regulation condition is an unrealistic aim given the competing needs of industry, community and ecology. The following discussion of flow requirements therefore focuses largely on maintenance of existing ecological values at a low level of risk. At the same time, consideration is given to some enhancement such as:

1. Improved habitat quantity and quality to support larger populations of native fish and greater diversity of macroinvertebrates;
2. Providing sufficient quantity and quality of water to maintain key ecological processes, *e.g.*:
    a. flows in winter and early spring to inundate fish spawning areas,
    b. flows to provide for fish passage over obstructions in late autumn and winter, and
    c. summer flows to maintain oxygen levels in pools;
3. Reducing introduced mosquitofish.

A summary of ecological values and proposed flow objectives is provided in Table 15 at the end of this section.

Riparian Zones

Foreshore condition surveys detail the general composition/vegetation complexes present in each reach, but do not provide detailed species lists, or transects to show position of species/complexes relative to the channel. Because definitive water requirements are currently unknown for individual species, detailed vegetation and floristic data will not provide for a more accurate determination of flow requirements. The degree to which individual species rely on surface versus groundwater/soil moisture is unknown, and there is little empirical data on timing, frequency and duration of inundation for seed-set, recruitment or survival.

It is recommended that channel surveys for EWR and EWP determinations include identification of broad zonations of riparian vegetation and record their elevations on the cross-section maps. This will allow the calculation of stage heights (flows) to reach these vegetation zonations. A similar approach has already been used by DoW for a review of EWRs for the Lower Collie as a whole (refer Hardcastle *et al.* 2003). Until more precise scientific knowledge of specific flow requirements of riparian vegetation is available, this approach should be used to provide inundation flows to different zones (low/medium/high banks), based on current frequency and duration (WRM 2008). This is particularly important for Reach 1a, where much of the original native vegetation remains intact, and to aid any future restoration projects in reaches 1b, 2 and 3. Maintenance of active channel and winter medium flows would also assist in seed dispersal downstream. Hardcastle *et al.* (2003) considered that in the main channel of the Collie River below Burekup weir "the effects of poor catchment management exceeded the physical attributes representing stream morphology that would have been maintained by natural flows or the current flow regime." They also state that due to pool in-filling and active erosion, there is "a requirement for higher flows to maintain natural scour and enhance river form."

Deep-rooted trees and perennial vegetation on the floodplain are likely more reliant on groundwater (Groom *et al.* 2000, 2001), but may also use soil moisture and iver flood waters during winter, particularly the younger recruits. Due to the deeply incised nature of the channels, it is expected that a much greater volume of water is now necessary to overtop the banks and inundate floodplain vegetation compared with the historic condition. While regulation has no doubt reduced the frequency and duration of overbank flows, higher overland/sheet flows due to land clearing and higher than historic groundwater tables and groundwater recharge in area has likely mitigated this reduction. Flow releases to inundate floodplain vegetation may in fact be detrimental given the volume required and associated erosive power in channels that are already erosion-prone channel. There is also the issue of undesirable flooding of agricultural lands.

The flow requirements for terrestrial fauna dependent on riparian zones are also unknown. Until such information becomes available, it is assumed that flows to maintain the riparian zone will adequately provide for water requirements of the dependent fauna. The literature consistently notes a close association between the condition of the riparian zone and the fauna it supports, the inference being, that if the riparian zone is maintained, then the fauna will be protected (WRM 2008).

Macroinvertebrates

Life History Characteristics

Spring-summer spawning is a common life history characteristic of many aquatic macroinvertebrates (WR 2008). Approximately 75% of species recorded in each reach surveyed are known to breed during spring-summer. Only approximately 20% are capable of breeding year-round or at multiple times per year. Fewer than 5% breed during the wetter winter months. Therefore, some spring-summer flow should be maintained to provide breeding habitat for the majority of species.

Around 20% of the macroinvertebrates have life history traits which would allow them to survive periods of seasonal drying. These are considered 'permanent' residents which can survive by burrowing into moist bottom and/or bank sediments, or have modifications to avoid desiccation (*i.e.* water-tight seals on shells; resistant eggs). They include most crustaceans, water mites (Acarina), aquatic snails (Gastropoda) and aquatic worms (Oligochaeta). As 'permanent' residents they are particularly susceptible to disturbance and changes in water quality.

By contrast, all insects recorded were considered to be 'temporary' residents with highly mobile adult phases that allow them to avoid adverse environmental conditions and reinvade from nearby habitats, once conditions improve (WRM 2006b). Though temporary residents are typically considered at lower risk from perturbations, this assumes adequate habitat is maintained close enough to afford refuge and/or enable re-colonisation. Permanent pools within an otherwise dry channel can also provide 'refuge' if they lie outside the influence of disturbance. Larval stages can re-invade either by drift (passive dispersal with water flow) or active swimming or walking along the stream bed. How close these 'refuges' need to be is dependent on the dispersal capabilities of individual species and the ability of drifting larvae to settle onto substrates. For most Australian, let alone south-west species, this is largely unknown (Downes *et al.* 2005).

In upland jarrah forest catchments to the north there is already some evidence to suggest that climate change may be affecting life-cycles of some aquatic macroinvertebrates (WRM 2006b). Some species are thought to be emerging earlier, while for others the season is now often too short for them to complete their lifecycles. Reduced flows due to increased abstraction from impoundments could have a similar effect in reaches where there are summer releases. If the winter-spring rainfall season is too short, then streams may dry before eggs and nymphs can develop (WRM 2006b). Species that recruit late and grow slowly through summer are generally at greater risk if drought conditions cause river pools to dry completely. Therefore maintenance of flow permanence would be beneficial to these species. This is particularly of issue for species that re-colonise/re-invade each year. Such species cannot withstand prolonged periods of drying. They usually have winged adult stages that take refuge in nearby more permanent streams/pools and return each year to lay eggs once flows return. If refuges also dry, or if water quality in refuges is reduced, then there will be no adults to return (WRM 2006b).

Habitat Complexity

Maintenance of macroinvertebrate diversity is dependent on maintenance of habitat complexity and diversity (Humphries *et al.* 1996, Kay *et al.* 2000). Many macroinvertebrates are essentially restricted to specific habitats *e.g.* snags and macrophytes in slow-flowing sections, gravel and rocks in fast flow, or sandy bottom substrates in slow to intermediate flows. The amount of shelter and food afforded by bankside and trailing vegetation as well as fallen debris will also determine taxa present, typically with greater diversity at sites with more remnant vegetation. For example, the freshwater shrimp *Palaemonetes australis*, is typically associated with snags, trailing vegetation and aquatic macrophytes (Gooderham & Tsyrlin 2002). Many leptophlebiid mayfly, dragonfly, damselfly, chironomid and caddisfly species prefer waters with a high abundance of wood and aquatic plants. Other caddis-flies such as *Taschorema pallescens* and *Smicrophylax australis* prefer rock and cobble substrates in high flow zones. *T. pallescens* and *S. australis* depend on the constant flow of water for delivery of oxygen, attaching themselves to rocks to spin nets for catching prey and plant material as it is swept past. They are not common in heavily polluted or stagnant waters. High diversity and abundance of EPT taxa is therefore likely a function of flow permanence.

It is therefore important to maintain sufficient flows to ensure snags, rocks, macrophytes and some overhanging riparian vegetation remains inundated. This will ensure a diversity of in-stream habitats is maintained.

Riffle zones are also regarded as highly productive habitat for macroinvertebrates (Brown & Brussock 1991) and for a perennial system, it is important to maintain coverage of riffles to maintain biodiversity. As water levels would naturally be lower in summer, it is not considered necessary to inundate the whole width of the riffle during low flow summer months. Rather, an average depth of 5 cm with a 50% coverage of the riffle is considered adequate to maintain a low-flow summer channel over riffle zones and is recommended as the minimum necessary to support benthic invertebrate communities (Storey *et al.* 2001). In winter however, these flows should be increased to a 100% lateral coverage with an average depth of 5 cm.

Freshwater Mussels

The priority 4 freshwater mussel *Westralunio carteri* is a filter feeder and vulnerable to water pollutants and sedimentation. It prefers shallow water habitats with stable, sandy or muddy bottoms and inhabits both permanent and seasonal rivers. It can survive prolonged periods of drought by burrowing into bottom muds and sealing the bivalve. It may thus survive potential drawdown of river pools. It is intolerant of high salinity but levels would likely need to reach 4,000 µS/cm (~2,500 mg/L) or greater before causing fatality (Bailey *et al.* 2002).

Of particular concern in regulated rivers is the fact that as part of their life cycle, these mussels have an early larval phase that is parasitic on the gills of native freshwater fish. This parasitism is the subject of current research by the Centre for Fish and Fisheries Research at Murdoch University (www.cffr.murdoch.edu.au/). Fish appear to be essential for completion of the mussels' life cycle. Mussels may also play an important role in maintaining water quality in the pools which provide refuge for fishes over summer. Mussels also provide a food source for native cobbler and water rats.

Barriers to upstream movement of fish may therefore also restrict gene flow between mussel populations, limit upstream-downstream recruitment of mussels, restrict distributions and prevent recolonisation. As well as weirs and dams, barriers include low flow regimes that make natural barriers (waterfalls, riffle zones) impassable for fish.

Gondwanic Fauna

Gondwanic fauna are relict fauna that have survived from an age that was typically more humid and wetter, with a less markedly seasonal climate than that which prevails today. As the climate became drier and environments fire-prone, relict fauna were increasingly restricted to specialized micro-habitats in damp, wet, poorly-drained areas such as swamps, winter-wet depressions and pools on granite outcrops (York Main 1996). Catchments or habitats that support a number of Gondwanic biota are considered important as they have increasingly significant conservation and National Estate value as more and more habitat is lost to development (Main 1996).

Most Gondwanic species are believed to require permanently damp, if not flowing, habitats. Gripopterygid stoneflies for example, are typical of high-current habitats in seasonal headwater streams of the jarrah forest. Others such as the dragonflies *Austrosynthemis cyanitincta*, *Hesperocordulia berthoudi* and *Austrogomphus collaris* and the damselfly *Austroaeschna anacantha* require permanent water. Of these, *A. cyanitincta* and *H. berthoudi* appear to require permanent rapid streams, rather than slow-moving water bodies. Changes in flow velocity as well as periodicity have the potential to adversely affect these macroinvertebrates.

Crayfish

Gilgies (*Cherax quinquecarinatus*), which were only abundant in Reach 1a below Harris Dam, are known to inhabit a wide range of waterbodies, from semi-permanent swamps to deep rivers (Austin & Knott 1996). They have a well developed burrowing ability and are able to withstand periods of low water level by retreating into burrows until flows return. They are able to withstand prolonged periods of drought so long as burrows remain damp and their gills stay hydrated. They have an extended late winter-summer spawning period (with multiple spawning events), and relatively quick maturation, breeding at the end of their second year (Beatty *et al.* 2005). Gilgies are more commonly found in areas with higher flow velocity and higher dissolved oxygen concentrations (Lynas *et al.* 2006).

Though capable of surviving in lower oxygen environments than gilgies, marron (*Cherax cainii*) are believed to be generally more sensitive to environmental fluctuations than are gilgies (see Morrissy *et al.* 1984, Holdich & Lowery 1988). They have a single springtime breeding season and there is a tendency for breeding failure in highly eutrophic waters (Morrissy 1983). Unlike gilgies, the burrowing habit in marron is not strongly developed. Therefore, permanent flows or access to pools or shallow groundwater is required to maintain marron populations.

Both marron and gilgies tend to be more abundant in streams and rivers with high diversity of in-stream habitats such as snags, rocks, boulders, emergent and submerged macrophytes and trailing riparian vegetation. As noted previously, the reasons for the low crayfish numbers in reaches 1b, 2 and 3 are unknown. A combination of factors may be responsible; poor habitat condition, altered substrate composition, poor water quality, and/or predation by redfin perch and trout.

Fish

Native Fish

All native fish recorded require permanent water, only colonising seasonal streams from adjacent permanent waters during wet season flows or residing in permanent 'refuge' pools during summer. Components of the biology of native fish species most likely to be affected by altered flow regimes are migration and reproduction/access to spawning habitat (WRM 2008). Maintenance of winter flows is necessary to cue upstream reproductive migration in western minnows and nightfish. Sufficient depth of water must also be maintained to 'drown-out' obstacles to fish passage such as riffles and snags *etc* and to inundate trailing riparian vegetation favoured by western minnow as spawning habitat. As noted by WRM (2003), the degraded riparian zone in reaches 1b and 2 (and also Reach 3) will limit the amount of spawning habitat available for native species in winter, and this will ultimately flow on to affect populations of these species.

The freshwater cobbler is an inhabitant of deeper pools. It typically spawns in pools during summer, and therefore would need deep, permanent water at this time of year to ensure successful recruitment. It is not known if scouring flows from Wellington have a detrimental effect on cobbler populations in the lower Collie. Scour flows of ca. 500 ML/day were released between June and September 2008 (Figure 5). Channel profile would need to be surveyed to estimate resultant stage heights and water velocities in downstream pools and their likely effect on cobbler. Higher flows in June-September would be expected as part of the natural hydrograph. Dependent on the magnitude, they would not normally be seen as a threat to cobbler nests as cobbler are believed to breed over summer, *i.e.* November to January (Morrison 1988, Morgan 1998). However, the presence of a juvenile during the current study in November, suggests cobbler may be breeding earlier in the year than previously thought. This may represent a change in reproductive behaviour in response to changing flow patterns, though the presence of a single juvenile specimen is far from conclusive. Of greater influence on survival of juvenile cobbler may be salinity levels. The tolerance of juveniles to elevated salinity is unknown, and winter scour flows have elevated salinities.

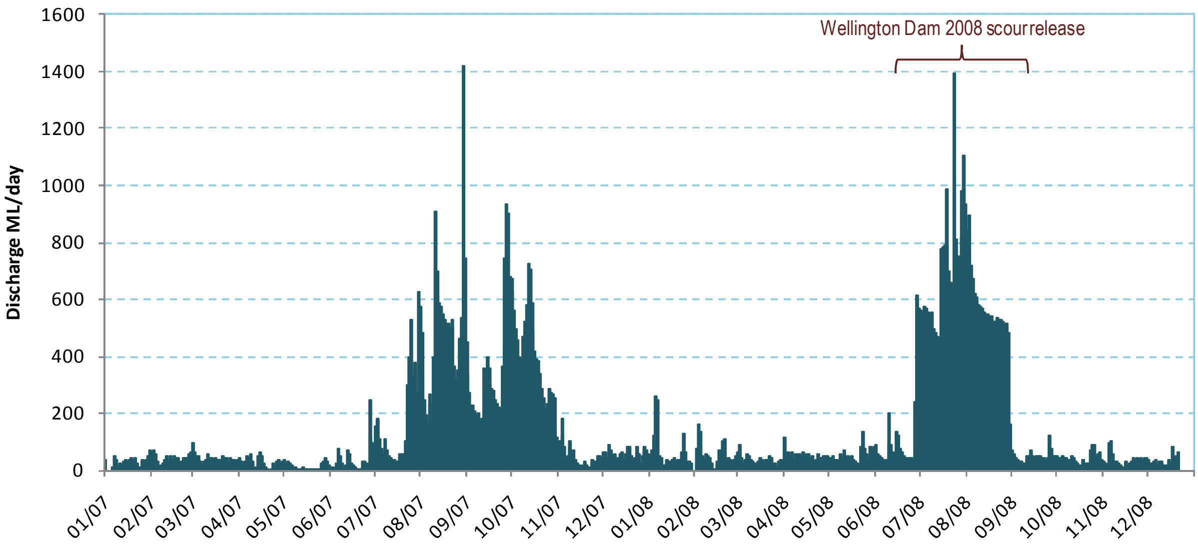

Figure 5. Telemetered discharge (ML) at gauging station 612043, Rose Road, approximately 7km below reach 1B. Data are total daily discharge for the period 1/1/07 to 31/12/08.

In regard to low flows, WRM (2008) considered a minimum depth of 20 cm over riffles as adequate for passage of larger fish species (*e.g.* cobbler) to maintain current fish diversity. Conservatively, this is also recommened for the current reaches and a shallow flow threshold of 10 cm over riffles for smaller species. Although minnows, pygmy perch and nightfish have been observed to negotiate waters of only 1 cm depth, they are likely to do so only under duress and such shallow waters are considered unsuitable for spawning and successful recruitment (WRM 2008). Hardcastle *et al.* (2003) have recommend flows to meet EWRs for fish passage in the lower Collie as a whole. However, to definitively establish the minimum flows required for fish passage in the current reaches, it would be necessary to conduct field trials to observe persistence of low-flow passages, measure water depth, velocity and height of jump-ups under different flow scenarios (Storey 2003).

Predictable winter/spring flows must also be maintained to ensure breeding success and strong recruitment. If water levels fall too soon, or fluctuate greatly, eggs may be left dry and desiccate. The authors consider the current winter flow regime (refer Figure 5) to be detrimental to downstream ecosystems. For example, in June 2008, scour release resulted in a ramp-up in flows from <50 ML/day to 600 ML/day, or approximately 7 m^3/sec, over a very short time period (Figure 5). Cessation of scour flows was similarly abrupt in September. This regime has implications for channel erosion, bank slumping, fish stranding, dehydration of fish/eggs *etc.* It is strongly recommended that the rise and fall of the hydrograph mimick that of the natural hydrograph.

As discussed by WRM (2008), the mode of delivery of winter flows to provide for fish passage is also a critical issue for any river system. Flows should be delivered in pulses to provide sufficient depth and time for fish to negotiate natural and man-made obstacles. The duration of each pulse may need to be several hours (or greater) to allow fish to negotiate all potential obstacles along a river reach. Retention of water levels that maintain summer pools can also be important to ensure habitat area is adequate to support populations of fish year-round.

Introduced Fish

Modifications to flow regimes may have significant implications for the dynamics and management of introduced mosquitofish populations. A combination of flow regimes is required to control mosquitofish (WRM 2008). It is suggested that the maintenance of winter spates is necessary to restore/maintain natural habitat characteristics in the lower reaches and provide increased flows which are unfavourable for these fish (Pusey *et al.* 1989). In addition, a period of zero flow days in summer would also be required. These flow recommendations would reduce the suitability of the system for proliferation of the mosquitofish.

Flows to maintain some ecological values may support other elements which may not be so desirable. For instance, maintaining populations of native fish, particularly providing sufficient flows for migration and spawning of cobbler will likely benefit all the introduced species (redfin perch, rainbow trout, mosquitofish), which ultimately may adversely impact on native fish – particularly pygmy perch and western minnow (WRM 2003).

Frogs

As with flows to inundate riparian vegetation, flow releases to inundate floodplain vegetation must be carefully considered if undesirable flooding of adjoining agricultural is to be avoided. The channels in all reaches are deeply incised and the volume of water needed to overtop banks is likely to be significantly greater than the historic condition. It is considered that local runoff and seeps coupled with (likely) higher water tables would be sufficient to maintain existing floodplain habitat for frogs and tadpoles in coastal plain reaches.

Salinity is another issue. Although adults can survive some salt, the juvenile stages require freshwater for survival. Changes in flow that change the winter/spring salinity have the potential to adversely affect frog populations. A reduction in flushing would adversely affect communities through the build-up of salt. Unfortunately, salinity thresholds of tadpoles and juveniles are not known.

Water Rats

Water rats are common around coastal Australia and New Guinea, occurring in a wide range of coastal, brackish and freshwater environments (Watts & Aslin 1981). Water rats require access to permanent water for feeding and to keep cool over the summer months; they suffer from heat stress if access to permanent pools is lost. Other threats are loss of habitat through clearing and grazing and loss of aquatic food sources due to secondary salinisation (Lee 1995). They are omnivorous, feeding on crayfish, mussels, fish, plants, water beetles, dragonflies and smaller mammals and birds. EWRs to maintain these prey items will provide for their diet. Breeding can occur throughout the year, but more typically in spring. They build nests at the ends of tunnels dug into banks near tree roots or in hollow logs. Therefore, there is a requirement for stable banks, tree roots and large woody debris (WRM 2007).

Water Quality

Although flows to control water quality issues are not considered an EWR, they may be recommended as "mitigation flows" to prevent water quality problems (*e.g.* salinity, nutrients, low dissolved oxygen) which may place existing ecological values at a high level of risk. Flow regulation can adversely affect downstream water quality through the concentration of salt and nutrients when water levels are reduced. Clearing for agriculture results in increased surface run-off and inflow, and this in turn can lead to higher sediment and nutrient loading, and increased turbidity and salinity in riverine environments. At the same time, regulation by dams or groundwater abstraction can reduce the input of good quality water that is low in nutrients, reducing flushing. This is particularly relevant to any future proposals for greater regulation of freshwater tributaries along the now largely brackish-saline Collie River. While dams may serve to limit flow of poor quality water from the upper catchments, they also reduce flushing and thereby encourage the accumulation of organic debris and sediments in channel pools, which ultimately reduces aquatic habitat diversity and exacerbates already poor water quality.

Salinity

If effective, proposed diversions to reduce salt loads into Wellington Dam will reduce salinity in the Lower Collie in the long term. Salinities recorded in all four reaches were higher than ANZECC/ARMCANZ (2000) guidelines recommended for freshwater systems in southwestern Australia. There is a general acceptance that when conductivity is less than 1500 μS/cm, freshwater ecosystems experience little ecological stress (Hart *et al.* 1991, Horrigan *et al.* 2005). Salinity levels will vary due to natural salinity of ground and surface waters, secondary salinisation associated with land clearing, ponding of rainfall in winter/spring and evapo-concentration of salts as water levels recede over summer. There is little published information on the sensitivity of Western Australian freshwater organisms to increases in salinity and few studies on sub-lethal or long-term effects on more sensitive life stages (WRM 2006b). ANZECC/ARMCANZ (2000) give a maximum trigger value of 1500 μS/cm, with the caveat that levels can rise to >3,000 μS/cm due to evapo-concentration over summer. Bailey *et al.* (2002) reported that reduced abundance of 80 - 90% has been recorded in many invertebrate species following rapid increases in salinity from around 300 to 2,000 μS/cm over a period of days.

In inland waters, maximum aquatic biodiversity is typically recorded when salinities are less than 3,000 μS/cm (2,000 mg/L TDS). Horrigan *et al.* (2005) found significant shifts in community composition as salinity reached 800 - 1,000 μS/cm. They also noted that changes in composition occurred at lower salinity but were more subtle, resulting in "the steady substitute of salt sensitive taxa by opportunistic and salt tolerant taxa" (Horrigan *et al.* 2005). Thus while community composition changed, species richness remained more or less the same. Increasing salinities likely result in the proliferation of nuisance groups such as mosquitoes (Culicidae) and midges (Chironomidae & Ceratopogonidae), and increases in other tolerant genera, *i.e.* water fleas (Cladocera), seed shrimps (Ostracoda) and ceinid amphipods (Bailey *et al.* 2002). In more saline wheatbelt wetlands, Pinder *et al.* (2005) found similar shifts and a decline in total species richness above ~3,900 μS/cm (2,600 mg/L). While many south-west species are likely salt-tolerant to some degree, "many species are at risk of regional extinction as salinisation becomes more widespread" (Pinder *et al.* 2005).

Most adult native fish species in south-western Australia appear to be able to withstand relatively high salinity. In a recent study on salinity tolerances of native south-west fishes, Beatty *et al.* (2008) reported an upper limit of 14,600 mg/L[4] (~21,500 µS/cm) for juvenile and adult western minnows and pygmy perch. However, it is likely that sub-lethal effects occur at considerabley lower salinity levels, in particular for eggs and larvae. There is also the potential for loss of invertebrate prey at lower salinities which may have considerable impact on the mostly omnivorous native fish fauna (Beatty *et al.* 2008).

In regard to EWRs, it is recommended that flows of fresh water be maintained in winter/spring to ensure successful reproduction and survival of more sensitive life stages. This may be met by ensuring there is access to seasonal freshwater tributaries for spawning, or maintaining river channel winter flows comprised of freshwater runoff (WRM 2008).

Dissolved Oxygen and Nutrients

No nutrient data were sourced or collected for the current reaches, however, it is likely that there is runoff of nutrients from the surrounding catchment associated with agricultural practices. Concentration of residual nutrients in pools during summer poses a risk to the water quality of these critical refugia for aquatic fauna. Excessive enrichment can be detrimental to aquatic fauna both directly and indirectly. High levels of ammonia (NH_3) for example, can be toxic to aquatic fauna (fish and macroinvertebrates) through deleterious effects on respiratory systems. Nutrient status fundamentally influences community metabolism (photosynthesis and respiration), which determines the oxygen status. Adequate concentrations of dissolved oxygen (DO) are fundamental for the survival of aquatic species and for the maintenance of ecological processes. In rivers where rates of metabolism are high, exceedingly low overnight DO levels can result and be lethal for aquatic fauna. Sufficient DO over 24 hours is a fundamental requirement of aquatic fauna. Current ANZECC/ARMCANZ (2000) guidelines recommend day-time DO levels should not be permitted to fall below 6 mg/L or 80-90% saturation. While night-time minima are not specified, ANZECC/ ARMCANZ (2000) note that levels below 5 mg/L are likely stressful to many aquatic species. Hypoxia and anoxia not only causes the localized extinction of fauna, but also results in desorption (release) of nutrients (*e.g.* phosphorus & ammonium) and heavy metals (*e.g.* from fertilizers) from sediments causing further water quality problems.

Flows to flush pools in autumn through spring would be needed to remove accumulated nutrients as well as maintain dissolved oxygen levels. This is of particular importance for Reach 1a, where accumulation of organic debris in pools and build-up of macrophyte growth within the main channel may be contributing to low DO levels.

Carbon Sources

The source and flux of carbon in Reach 1a on the Harris River would be best described by the River Continuum Concept (refer section 'Carbon Sources/Processing', above). The Harris River retains relatively healthy remnant terrestrial vegetation, with the majority being state forest. Therefore, terrestrial organic matter entering the river in these upper reaches is likely the main source of carbon and will also provide carbon to lower reaches and East Collie River. However, impoundments by Wellington Dam and Burekup weir likely disrupt the flow of carbon downstream, and act as carbon sinks. Significant land-clearing in the Lower Collie will also lessen the contribution of terrestrial vegetation to aquatic food webs. Therefore, in reaches 1b, 2 and 3, the Riverine Productivity Model likely plays a greater role as the relative contribution of in-stream algal carbon to food webs increases. Terrestrial carbon will still enter these reaches in the form of animal manures and organic carbon in soils washed in by overland run-off and anthropogenic sources of nutrients will also support coastal plain food webs. Regular flooding likely still occurs on the lower systems maintaining river-floodplain connection. However, the deeply down-cut channels on the coastal plain may mean transfer of carbon and nutrients from the river to the floodplain has been reduced.

[4] Seawater = 35,000 mg/L = ~51,470 µS/cm (ANZECC/ARMCANZ 2000).

Based on Storey *et al.* (2001), Storey and Davies (2002) and WRM (2005b), flows recommended for macroinvertebrates combined with fish passage flows should be adequate to maintain upstream-downstream energy linkages (winter through to spring) in the current reaches. Higher winter flows provided for fish passage should also be adequate to flush the channel and inundate mid and lower benches and thereby maintain allochthonous litter transfer. Overland runoff will maintain lateral carbon input from the floodplain.

Table 15. Ecological values and flow objectives determined for the current study. Reach 1a = Harris River below Norm Rd; Reach 1b = lower Collie River below Burekup weir; Reach 2 = lower Collie River west of SW Hwy; Reach 3 = Henty Brook west of SW Hwy.

FLOW COMPONENT	ECOLOGICAL ATTRIBUTE/VALUE	ECOLOGICAL OBJECTIVE	REACH	SEASON (DURATION)	TIME SERIES (PULSE/SPELLS)	HYDRAULIC METRIC	CONSEQUENCE OF NOT MEETING OBJECTIVE
Summer Base Flow	Fish and invertebrate fauna diversity	Maintenance of permanent pools	1a 1b 2 3	Summer			Loss of species that depend on permanent water.
	Invertebrate diversity	Maintain gravel runs and riffles as biodiversity 'hotspots'	1a 1b 2 3	Summer	Flow duration	Minimum stage height during summer to maintain current area of gravel runs and riffles to a depth of 0.05 m and 50% lateral coverage	Loss of biodiversity.
	Aquatic fauna - invertebrates, fish, frogs	Maintain pool volume through summer as a drought refuge for aquatic fauna	1a 1b 2 3	Summer	Baseflow		Loss of pools and species requiring permanent water.
Summer Low Flow	Native fish; aquatic invertebrate fauna diversity; pool water quality	Flows to prevent significant stratification or anoxia in pools	1a 1b 2 3	Summer	Flow duration	Maintain DO levels > 5 mg/L; accepted that a bulk flow velocity of 0.01 m/sec in pools is sufficient to maintain DO levels	Pool anoxia with fish kills. Sub-lethal effects to eggs/larvae. Aquatic macroinvertebrates – loss of biota/change in composition to those with strategies to tolerate low oxygen levels.
Fish Passage Flow	Native fish diversity	Provide passage for small bodied fish (i.e. western minnow, pygmy perch and nightfish), moving upstream from late autumn through winter and into early spring across obstacles such as shallow riffles and runs.	1a 1b 2 3	late autumn through winter and into early spring	events (size and frequency) / duration	Minimum depth over obstacles of ca. 0.1 m from late May to late August for fish movement	Loss of migratory species from parts of the system if passage restricted. Reduced connectivity.
		Provide passage for large bodied fish (i.e. cobbler), moving upstream from late autumn through winter and into early spring across obstacles such as shallow riffles and runs.	1b 2	late autumn through winter and into early spring	events (size and frequency) / duration	Minimum depth over obstacles of ca. 0.2 m from late May to late August for fish movement	Loss of migratory species from parts of the system if passage restricted. Reduced connectivity.
Stress Relief Flow	Pool ecology	Maintain oxygen, temp etc, flush contaminants	1a 1b 2 3	Late autumn, early winter	Small events	Maintain frequency, timing, duration of early season freshers	Reduced flow period and extended period of summer stress conditions – threats to ecological values in pools.
Winter Low Flow	Native Fish	Stage height to ensure marginal reeds/rushes are trailing & thereby providing fish cover and spawning habitat	1a 1b 2 3	Winter	Flow duration	Duration of baseflow sufficient to inundate trailing vegetation – based on elevation of this habitat on x-sections.	Insufficient flows will leave trailing vegetation above water and not accessible; insufficient continuous duration may expose and dehydrate eggs spawned onto vegetation; increased risk of predation/competition with other fish (introduced) species.

FLOW COMPONENT	ECOLOGICAL ATTRIBUTE/VALUE	ECOLOGICAL OBJECTIVE	REACH	SEASON (DURATION)	TIME SERIES (PULSE/SPELLS)	HYDRAULIC METRIC	CONSEQUENCE OF NOT MEETING OBJECTIVE
	Vegetation	Inundate emergent macrophytes and aquatic plants	1a 1b 2 3	Winter	Flow duration	Inundate lower benches in winter	Loss of biodiversity
	Invertebrates	Maintain gravel runs and riffles as biodiversity 'hotspots'.	1a 1b 2 3	Winter	Flow duration	Inundate riffles in winter (0.05 m stage height over riffles with 100% lateral coverage)	Loss of biodiversity
	Water Rats (and frogs)	Stage height to ensure marginal reeds/rushes are trailing & thereby providing cover.	1b	Winter	Flow duration	Duration of baseflow sufficient to inundate trailing vegetation – based on elevation on x-sections.	Loss of biodiversity
Winter Medium Flow	Vegetation	Riparian vegetation – main channel lower bank & emergent vegetation	1a 1b 2 3	Winter	Flow duration	Flood lower banks in winter	Change from historic water regime = change in plant community (terrestrialisation) with associated change in structure. Enhanced opportunity for terrestrial weeds (e.g. grasses, *Watsonia*). Riparian vegetation provides aquatic habitat & material to support detrital food webs.
	Native fish	As for winter low flows					
	Process	Seasonal inundation of benches for allochthonous litter transfer. Predictions of Riverine Productivity Model; seasonal inundation & recession 'collects' detrital material in main channel which supports food webs.	1a 1b 2 3	Winter	Medium wet season events	Inundate lower benches based on elevation of benches in x-sections	Detrital material important in food webs. Loss of this material may limit abundance and/or presence of some species.
Winter High Flow	Channel morphology	Maintain pools & channel form. Pools provide refugia for fauna in summer & require regular scouring to prevent excessive build up and infilling.	1a 1b 2 3	Winter	Event magnitude/ frequency	Channel forming flows – flows to active channel stage height	Loss of pool depth = reduced carrying capacity for fish, loss of summer refugia for fish and water rats, greater encroachment by riparian vegetation, higher BOD with associated risk of low DO in summer, loss of benthic fauna due to smothering by fine sediment build up, smothering of snags in pools = reduced habitat.
		Prevent incursion of riparian vegetation into channel. There is a dynamic relationship between flow, sediment deposition & vegetation encroachment on the channel.	1b 2 3	Winter	Event magnitude/ frequency	Channel forming flows – flows to active channel stage height	Area of active channel will decrease. Peripheral velocities will be reduced resulting in more sediment deposited & weed incursion.

FLOW COMPONENT	ECOLOGICAL ATTRIBUTE/VALUE	ECOLOGICAL OBJECTIVE	REACH	SEASON (DURATION)	TIME SERIES (PULSE/SPELLS)	HYDRAULIC METRIC	CONSEQUENCE OF NOT MEETING OBJECTIVE
	Predictions of Flood Pulse Concept; seasonal inundation and recession "collects" detrital material in main channel which supports food webs	Seasonal inundation of higher (and lower) benches for allochthonous litter transfer.	1a 1b 2 3	Winter	Medium wet season events	Inundate higher benches in winter	Detrital material important in food webs. Loss of this material may limit abundance and/or presence of some species.

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APPENDIX 1 MACROINVERTEBRATE SPECIES RECORDED FROM NOV. 2008 FIELD SURVEY

Systematic list of macroinvertebrate taxa recorded during the current field survey in November 2008. Values are log-abundance, *i.e.* log10 scale where 1 = 1 individuals, 2 = 2-10, 3 = 11-100, 4 = 101-1000, 5 = >1001. F = female; Imm. = immature; L = larvae; P = pupa; V = voucher code. Conservation category (Cons. Cat.): Aus = cosmopolitan/Australia and beyond, however not necessarily worldwide; WA = Western Australia only; SW = endemic to south-western WA; Indet = indeterminate.

TAXA	Reach 1a						Ave.	Reach 1b						Ave.	Reach 2						Ave.	Reach 3						Ave.
	1a-1	1a-2	1a-3	1a-4	1a-5	1a-6		1b-1	1b-2	1b-3	1b-4	1b-5	1b-6		2-1	2-2	2-3	2-4	2-5	2-6		3-1	3-2	3-3	3-4	3-5	3-6	
PORIFERA																												
Spongillidae																												
Spongillidae sp.								1	1					**1**														
BIVALVIA																												
Sphaeridae																												
Musculium kendricki								2			1			**2**				1			**1**	3	2	2	1	1	2	**2**
Hyriidae																												
Westralunio carteri											3	3	3	**3**		2					**1**			3	3			**3**
GASTROPODA																												
Ancylidae																												
Ferrissia petterdi								1	1			1	1	**1**													1	**1**
Lymnaeidae																												
Pseudosuccinea collumella															1						**1**	1						
Lymnaeidae sp.																											2	**2**
Austropeplea lessoni																											2	**2**
Planorbidae																												
Glyptophysa sp.																	1				**1**	3	2	2			2	**2**
Physidae																												
Physa acuta																									3			**3**
ANNELIDA																												
OLIGOCHAETA																												
Oligochaeta spp.	3	2	1	2	1	3	**2**	3	5	3	2	2		**3**	4			2	3		**3**	2	3	2	2	5	3	**3**
HIRUDINEA																												
Glossophonidae																												
Habeobdella stagni																	1				**1**							
CRUSTACEA																												
DECAPODA																												
Palaemonidae	2	2	2	3	2	2	**2**		1	3	3	3	2	**2**	2	3	2	4	3	3	**3**	2	2	3	2		1	**2**

TAXA	Reach 1a						Ave.	Reach 1b						Ave.	Reach 2						Ave.	Reach 3						Ave.
	1a-1	1a-2	1a-3	1a-4	1a-5	1a-6		1b-1	1b-2	1b-3	1b-4	1b-5	1b-6		2-1	2-2	2-3	2-4	2-5	2-6		3-1	3-2	3-3	3-4	3-5	3-6	
Parastacidae																												
Cherax quinquecarinatus	2	2	2	2	1	1	**2**		2					**2**			1				**1**						1	**1**
Cherax cainii				1			**1**													1	**1**							
OSTACODA										3	3			**3**		3				2	**3**	4	4	4	3			**4**
CLADOCERA		3					**3**																					
COPEPODA	3			3			**3**	3			4		4	**4**	4	4	3			3	**4**	3	3					**3**
AMPHIPODA																												
Perthidae																												
Perthia sp.	3	2	3	2	2	3	**3**	2					2	**2**								1	2		1		2	**2**
Austrochiltonia subtenius					1	2	**2**									1		2			**2**	2	2	1		2	2	**2**
ARACHNIDA																												
ORIBATIDA					2		**2**	1	2	1				**1**					2		**2**							
ACARINA																												
Hydracarina spp.								2		3	2	2	2	**2**		1	4	2	2		**2**						2	**2**
INSECTA																												
EPHEMEROPTERA																												
Ephemeroptera sp. (Imm.)																				2	**2**							
Caenidae																												
Tasmanocoenis tillyardi	2	3	2	3	3	3	**3**	4	4	3	4	4	3	**4**	3	2		2	2	2	**2**	2	4	4	4	3	3	**3**
Caenidae sp. (Imm.)																		1			**1**							
Baetidae																												
Cloeon sp.			2	2	2	2	**2**	3	4	3			3	**3**					2		**2**	2	3					**3**
Baetidae spp. (Imm./damaged)	1	2					**2**																					
Baetidae Genus 1.												1		**1**				2			**2**						3	**3**
Leptophlebiidae																												
Atalophlebia ?sp. AV17								2	3	2	3	2	1	**2**		2			2	2	**2**		3	3	3	2		**3**
Atalophlebia sp.																		3			**3**	2						**2**
PLECOPTERA																												
Gripopterygidae																												
Newmanoperla exigua		1	3				**2**		2					**2**									1		1	2		**1**
ODONATA																												
Zygoptera																												
Zygoptera spp. (Imm.)						1	**1**																1					**1**

TAXA	Reach 1a						Ave.	Reach 1b						Ave.	Reach 2						Ave.	Reach 3						Ave.
	1a-1	1a-2	1a-3	1a-4	1a-5	1a-6		1b-1	1b-2	1b-3	1b-4	1b-5	1b-6		2-1	2-2	2-3	2-4	2-5	2-6		3-1	3-2	3-3	3-4	3-5	3-6	
Coenagrionidae																												
Coenagrionidae spp. (Imm./damaged)		2	1				**2**																					
Ishnura heterostricta		2			1	2	**2**															1						**1**
Megapodagrionidae																												
Miniargiolestes minimus																							1					**1**
Telephlebiidae																												
Austroaeschna anacantha	2	2	2				**2**	3	3	1			2	**2**														
Anisoptera																												
Anisoptera spp. (Imm.)		1					**1**												1		**1**						1	**1**
Gomphidae																												
Austrogomphus collaris										1	1	3	2	**2**	2			1		2	**2**	1	2	2	2			**2**
Libellulidae																												
Orthetrum caledonicum																									2			**2**
Diplacodes haematodes																									1			**1**
Oxygastridae																												
Hesperocordulia berthoudi		2			2		**2**																		1			**1**
Synthemistidae																												
Austrosynthemis cyanitincta	2	1	2			1	**2**	1						**1**									2	2	2			**2**
HEMIPTERA																												
Veliidae																												
Microvelia sp. (F)	1						**1**																					
Microvelia peramoena					1		**1**				1			**1**														
Veliidae spp. (Imm.)				2			**2**								2						**2**							
Corixidae																												
Micronecta sp.																1		1	1		**1**	2		2				**2**
Diaprecoris sp. (Imm.)																		2			**2**							
Sigara mullaka															2						**2**			1				**1**
Corixidae sp. (Imm.)																		1	1		**1**	2						**2**
Notonectidae																												
Anisops sp. (F)																								1				**1**
Ochteridae																												
Megochteras occidentalis																			1		**1**							

TAXA	Reach 1a						Ave.	Reach 1b						Ave.	Reach 2						Ave.	Reach 3						Ave.
	1a-1	1a-2	1a-3	1a-4	1a-5	1a-6		1b-1	1b-2	1b-3	1b-4	1b-5	1b-6		2-1	2-2	2-3	2-4	2-5	2-6		3-1	3-2	3-3	3-4	3-5	3-6	
COLEOPTERA																												
Carabidae																												
Carabidae spp. (L)															1		1			1	**1**				1			**1**
Brentidae																												
Brentidae spp.	1						**1**										1				**1**							
Brentidae sp. (L)																	2				**2**		1					**1**
Dytiscidae																												
Allodessus bistrigatus					1		**1**								1	2	2		1	1	**1**	1		1	1	1	2	**1**
Hydrovatus sp. (L)						2	**2**				1			**1**		1	2	1			**1**			2				**2**
Limbodessus inornatus															1		2			1	**1**	1						**1**
Limbodessus shuckhardii													1	**1**		1					**1**						1	**1**
Limnoxenus sp. (L)																		1			**1**	1		1	1			**1**
Limnoxenus zealandicus																		1			**1**	1			2	1		**1**
Megaporus howitti															2		1				**2**				2			**2**
Necterosoma darwini															1						**1**	1			1			**1**
Necterosoma penicillatus																								1				**1**
Necterosoma sp. (L)																2					**2**					1		**1**
Platynectes sp. (L)																										1		**1**
Rhantus suturalis																									1			**1**
Rhantus sp. (L)																						1						**1**
Sternopriscus brownii																						1						**1**
Sternopriscus marginatus	2	2		1			**2**																					
Sternopriscus multimaculatus		1			1		**1**											2			**2**							
Sternopriscus sp. (L)		2	1	1	2	2	**2**	1			1	1		**1**		2	2	2	2	1	**2**	1	3	3	1	1	2	**2**
Tribe bidessini (L)															1		2				**2**							
Gyrinidae																												
Aulonogyrus/Macrogyrus sp. (L)				1			**1**															3	2	2	3	2	3	**3**
Aulonogyrus strigosus															1			2		2	**2**	2	1	1	3		3	**2**
Macrogyrus (Triblogyrus) sp.																						2	1		2		2	**2**
Hydrophilidae																												
Berosus sp. (L)								1						**1**														
Enchorus moculiceps																						1				1		**2**
Enchorus sp. (L)						1	**1**								1				1		**1**							

TAXA	Reach 1a						Ave.	Reach 1b						Ave.	Reach 2						Ave.	Reach 3						Ave.
	1a-1	1a-2	1a-3	1a-4	1a-5	1a-6		1b-1	1b-2	1b-3	1b-4	1b-5	1b-6		2-1	2-2	2-3	2-4	2-5	2-6		3-1	3-2	3-3	3-4	3-5	3-6	
Helochares sp. (L)																	3			2	**3**	1			2	2		**2**
Paracymus pygmaeus				1		2	**2**	1	1	1			1	**1**	2	2	2	2	2	2	**2**	1				2		**2**
Paracymus sp. (L)						1	**1**												1		**1**							
Paranacaena librida		1				2	**2**																					
Paranacaena spp. (damaged)																		1			**1**							
Hydrochidae																												
Hydrochus sp.										1				**1**	1		1	2	2		**2**							
Hydraenidae																												
Hydraena sp.									1					**1**														
Limnichidae																												
Limnichidae spp.																	1				**1**					1		**1**
DIPTERA																												
Diptera spp.																	1				**1**							
Athericidae																												
Athericidae sp.	2	3	2		2	1	**2**				1	1		**1**									1		2	2		**2**
Chironomidae																												
Chironomidae spp. (P)	2	2	2	1		2	**2**	2	2	2	4	2	2	**2**	2	2	2	2	2	2	**2**	2	2	1	3	2	2	**2**
Chironominae																												
Chironomus aff. altermans	2	2		1	2	1	**2**	3	3	3	3	2	3	**3**	2	4	3	2	2	3	**3**	3	3	3	3		3	**3**
Cladopelma curtivala					3		**3**				3	2	3	**3**		2	1	2	2	3	**2**		3	2	2		1	**2**
Cryptochironomus griseidorsum									2	2	2	1		**2**				2	2	2	**2**		2				1	**2**
Dicrotendipes conjunctus		1					**1**								2	3	2	2		2	**2**	1				1		**1**
Dicrotendipes sp.											1			**1**					1	2	**2**						1	**1**
Kiefferulus intertinctus	2				3		**3**																					
Paracladopelma sp. (VCD10)										2	2			**2**					1	3	**2**					1		**1**
Parachironomus sp. (VSCL35)																			1		**1**							
Polypedilum watsoni	3		1				**2**				1			**1**														
Polypedilum sp.	3	2	2	3	4	3	**3**	2			2	2		**2**			2		2	2	**2**			3				**3**
Riethia sp. (V4)	2		2			1	**2**																					
Rietha sp. (V5)	3	2	2				**2**																					
Stenochironomus sp. (V27)											1	1		**1**				1			**1**							
Stenochironomus sp. (V40)				1			**1**			2				**2**														
Cladotanytarsus sp.																	2	2		3	**2**		3	2	2		2	**2**

TAXA	Reach 1a						Ave.	Reach 1b						Ave.	Reach 2						Ave.	Reach 3						Ave.
	1a-1	1a-2	1a-3	1a-4	1a-5	1a-6		1b-1	1b-2	1b-3	1b-4	1b-5	1b-6		2-1	2-2	2-3	2-4	2-5	2-6		3-1	3-2	3-3	3-4	3-5	3-6	
Rheotanytarsus sp.	3	1	4		2	2	**2**		1	2		2	3	**2**	3	2		3	4	2	**3**					2	2	**2**
Stempellina sp.		2	2		2	1	**2**																					
Tanytarsus sp.	4	3	3	3	3	3	**3**	4	3	3	4	3	3	**3**	3	4	2	3	4	3	**3**	3	3	3	3	3	3	**3**
Orthocladiinae																												
Botryocladius bibulmun								3	2	2	2	1	3	**2**		1					**1**							
Cricotopus annuliventris	3	2	2	2	3	2	**2**	3	3	3	3	3	4	**3**	3	2		2	3	2	**2**	4	3	3	3	3	3	**3**
nr. *Gymnometriocnemus* (sp. 1)						1	**1**																					
Parakiefferiella sp. (nr. *variegatus*)	1		2			2	**2**	2		1				**2**												1		**1**
Paralimnophyes sp.		3		2		4	**3**										2		1		**2**							
Nanocladius sp. (VCD7)					1		**1**			1	1	2		**1**		1	1		1	1	**1**	1						**1**
Thienemanniella sp.	4	2	4	2	2	2	**3**	3	4	3	2	3	4	**3**	3		2	3	3		**3**	2	3	2	2	2	4	**3**
unknown genus (V15)		1					**1**																					
unknown genus (VSCL3)															2		2		2		**2**							
Coryoneura sp. (V49)		2		1	2	3	**2**				1			**1**			2		2	1	**2**	2						**2**
Tanypodinae																												
Ablabesmyia sp.	1						**1**																					
Larsia ?albiceps						2	**2**	1						**1**														
Paramerina levidensis	3	3	3	3	3	3	**3**	3	2	3	2	2	3	**3**	2			1			**2**	2	2	1	2		2	**2**
Procladius paludicola	1	3		1	3	2	**2**	1			2	2	2	**2**					1	2	**2**	2		2			2	**2**
Ceratopogonidae																												
Ceratopogoniinae spp.	2	2	3	2	2	2	**2**	2			4			**3**			2		2		**2**	1	2	1			2	**2**
Dasyheleinae spp.						2	**2**								1						**1**							
Ceratopogonidae spp. (P)	2						**2**						2	**2**											2		2	**2**
Culicidae																												
Anopheles sp.		2		1			**2**		1	3	2	1		**2**								2	2	2	2	1		**2**
Culicidae spp. (P)					2	2	**2**					2		**2**														
Dolichopodidae						2	**2**	1	1			1		**1**	3		2		3		**3**		2	3	3	2	3	**3**
Empididae	1						**1**						1	**1**	3	2					**3**							
Ephydridae																										1	1	**1**
Muscidae													1	**1**				1			**1**					1		**1**
Psychodidae															1	2					**2**		2	2		2		**2**
Simuliidae																												
Simulidae spp. (P)	2		2				**2**					1	2	**2**														
Simuliidae spp. (Imm.)	3		4	2			**3**	4	3	1			3	**3**				2		1	**2**	1			2		1	**1**

TAXA	Reach 1a						Ave.	Reach 1b						Ave.	Reach 2						Ave.	Reach 3						Ave.
	1a-1	1a-2	1a-3	1a-4	1a-5	1a-6		1b-1	1b-2	1b-3	1b-4	1b-5	1b-6		2-1	2-2	2-3	2-4	2-5	2-6		3-1	3-2	3-3	3-4	3-5	3-6	
Stratiomyidae						1	**1**																	1				**1**
Tipulidae													1	**1**	2	2	2	1		2	**2**		1	2	1		2	**2**
Tabanidae																									2			**2**
TRICHOPTERA																												
Trichoptera spp. (Imm.)																				1	**1**							
Ecnomidae																												
Ecnomus sp.			1				**1**		1	1	2			**1**	2	1		3	3		**2**	1			2	1	2	**2**
Hydrobiosidae																												
Taschorema pallescens								3	3	2		1	2	**2**														
Hydropsychidae																												
Cheumatopsyche sp. AV2	3						**3**	3	3	3		2	3	**3**	2					3	**3**	2	2		3	3	3	**3**
Smicrophylax australis	3	2	2				**2**																					
Smicrophylax ?*australis* (Imm.)			2				**2**		3					**3**														
Hydropyschidae spp. (Imm.)								1						**1**					2		**2**			2				**2**
Hydroptilidae																												
Acritoptila sp.		1		2	2	2	**2**			1	1			**1**				2	2	2	**2**	2	2		1			**2**
Hydroptilidae sp. (Imm.)		2					**2**						1	**1**		1			2		**2**							
Leptoceridae																												
Oecetis sp.	2	2	1	1	2		**2**		1		3	2	3	**2**		1	1	2		2	**2**		2	2	3	2	3	**2**
Condocerus aptus	2		2	1			**2**																					
Notoperata tenax	3		2				**3**					1		**1**									1	2	2	2	2	**2**
Notalina spirax															1					2	**2**			2				**2**
Notalina sp. AV16																			2		**2**	2						**2**
Trianodes sp.				1			**1**	2	2	2	2	3	3	**2**	1	2	2	3	3	3	**2**			2			2	**2**
Leptoceridae spp. (Imm.)	3		2			1	**2**	2	1	2		2		**2**						2	**2**		2	2		2		**2**
Philopotamidae																												
Hydrobiosella sp.								2						**2**														
LEPIDOPTERA																												
Pyralidae																												
Nymphulinae spp.					1		**1**			2			2	**2**	1		1				**1**							