Environmental values, flow related issues and objectives for the Canning River, Western Australia

From the Canning Dam to Kent St Weir

Department of Water

Environmental Water Report Series

Report No. EWR5

May 2007

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Acknowledgements

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ISSN 1833-6582 (pbk.).
Printed on recycled paper.

May, 2007

Subject of cover photograph
Freshwater cobbler (*Tandanus bostocki)*

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Summary

This document summarises the ecological and hydrological investigations undertaken on the Canning River. Where relevant, information from similar systems in the south west of Western Australia has been included. The document focuses on the key environmental attributes considered the most likely to be affected by the flow regime of the Canning River. These are:

- hydrology and channel morphology;
- macro-invertebrates;
- fish fauna;
- waterbirds;
- water quality;
- aquatic and riparian vegetation;
- ecological processes

Estuarine values have not been addressed as part of this study.

For each attribute (listed above) a description of its current state or condition is provided followed by a discussion on the effect of altered flows on the attribute. Based on this information, and through discussion with the Canning Environmental Flows Technical Working Group, flow objectives and considerations were developed and are presented for each attribute.

The flow objectives and considerations will guide the determination of ecological water requirements for the river, which will be used in developing a water resource management plan for the system.

1 Introduction

1.1 Responsibilities of the Department of Water

The Department of Water has the responsibility for the management of water resources in Western Australia. It is the lead agency for water resource assessment, protection and allocation and aims to serve the competing needs for water in the Western Australian community. The Department's water resource allocation responsibilities are governed by the recently amended *Rights in Water and Irrigation Act 1914.*

The Department seeks to balance the ecological needs and social expectations for water in the natural environment with society's need for water for economic benefit.

1.2 Canning River water Resource Management

A study to determine the ecological water requirements of the Canning River was conducted by Storey, Davies and Creagh in 2002. This study, using the limited hydrological information available at the time, estimated a minimum monthly flow rate to maintain the ecology of the Canning River.

The need to revise the ecological water requirements with more accurate hydraulic and hydrological measurement and analysis of the river system was identified in the *Caring for the Canning Management Plan* (Swan River Trust 2002*)* and the Swan Catchment Council's *Swan Region Catchment Management Plan for Natural Resource Management 2004*. As a result, the Canning Environmental Flows project was initiated, funded by the Natural Heritage Trust through the Swan Catchment Council, and managed by the Department of Water.

The development of ecological water requirements, along with the social and economic information, will provide the basis for developing a water resource management plan for the Canning River. The plan will identify the water resources and water regimes to be protected and define the water licensing policies for the river system.

1.3 Desired future state

In undisturbed environments, ecological water requirements are determined with the aim of protecting existing ecological values at a low level of risk (WRC 2000). The situation may be less well defined for systems that have been modified through regulation and/or as a result of land use changes, as is the case with the Canning River system. Where the environment has been disturbed, the ecological water requirements can be established to:

- maintain the current key ecological values at low risk;
- maintain and/or enhance current key ecological values;
- restore pre-existing or pre-disturbance ecological values; or

- provide for a combination of current key ecological values and key pre-existing natural ecological values.

In recognition of the long history of regulated flows in the Canning River and modification to the catchment, the ecological water requirements will aim to maintain and enhance the current key ecological values.

2 The Canning River catchment

2.1 The study area

The Canning River catchment is located in the south west of Western Australia, adjacent to, and within the Perth Metropolitan area. The catchment is comprised of the following nine major sub-catchments (Figure 1);

- Churchman Brook,
- Stony Brook;
- Ellis Brook;
- Bickley Brook;
- Wungong River;
- Lower Canning River;
- Yule Brook;
- Stinton Creek; and
- the urban drainage systems of Mill Street, Wilson, Collier Pines and Manning main drains.

The Canning Environmental Flows project focuses on the freshwater reach of the Canning River from the base of the Canning Dam to Kent St Weir. The Southern-Wungong River system, tributaries such as Churchman, Stony, Ellis and Bickley brooks and the estuarine areas downstream of Kent Street Weir were not considered during this project[1].

2.2 Catchment characteristics

The catchment is subject to a Mediterranean climate with cool wet winters and hot dry summers.

The headwaters of the Canning River are located on the Darling Plateau to the east of Perth. The river flows down the Darling Scarp, across the Swan Coastal Plain before discharging into the Swan-Canning estuary. The landscape of the Darling Plateau and Scarp consists of lateritic duricrust overlying granitic bedrock that is in places exposed, particularly in steep sided river valleys. The river and its tributaries in these parts of the catchment are typically seasonal, fast flowing systems with lateritic gravel and granitic pebble and bedrock substrates. The river channel is bedrock controlled in the upper reaches of the Canning River (Storey 1999).

The Swan Coastal Plain consists of deep highly leached sands of Pleistocene and more recent origins. Flow in the Canning River and its larger tributaries on the Swan Coastal Plain is typically permanent, primarily as a result of connectivity with

[1] Ecological water requirement studies for Munday, Churchman and Bickley Brooks have previously been completed (see Strategen 2004).

groundwater, with low flow velocity over alluvial sands and silt substrates (Storey 1999).

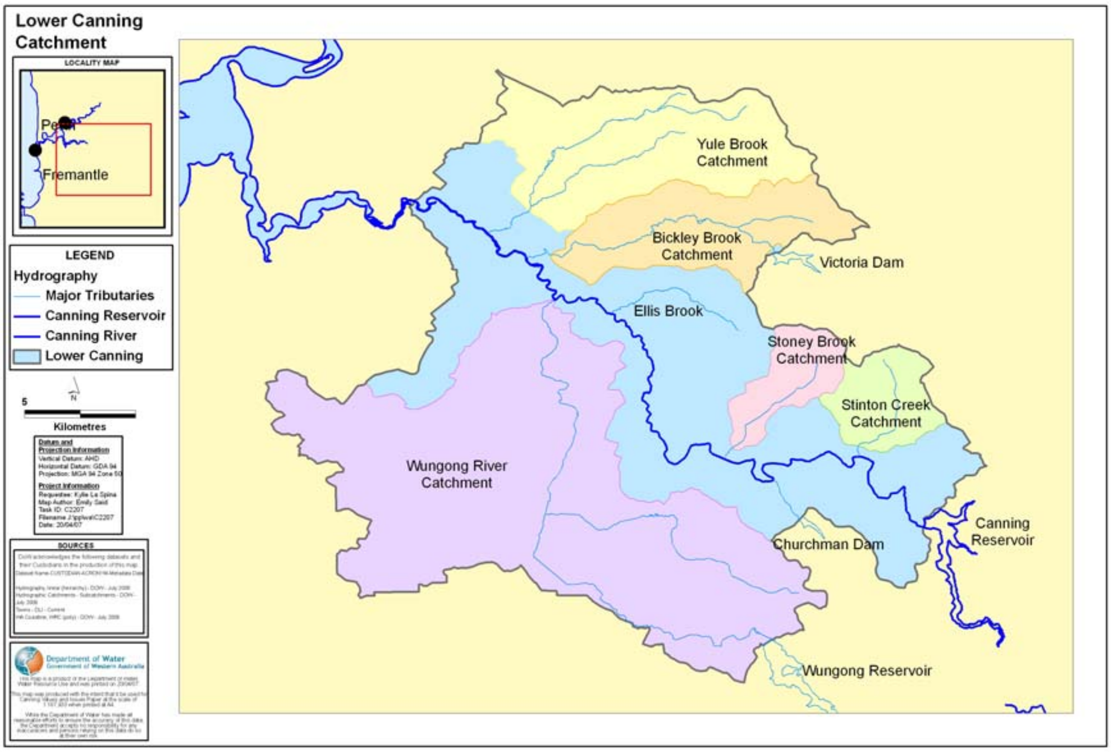

Figure 1: Map of the Lower Canning River catchment indicating the location and extent of sub-catchments.

2.3 Seasonal patterns of flow

The streamflow in the Canning River is highly seasonal with 93% of flow occurring between June and October (Figure 2). This seasonal pattern of flow is strongly correlated to mean precipitation and surface water runoff.

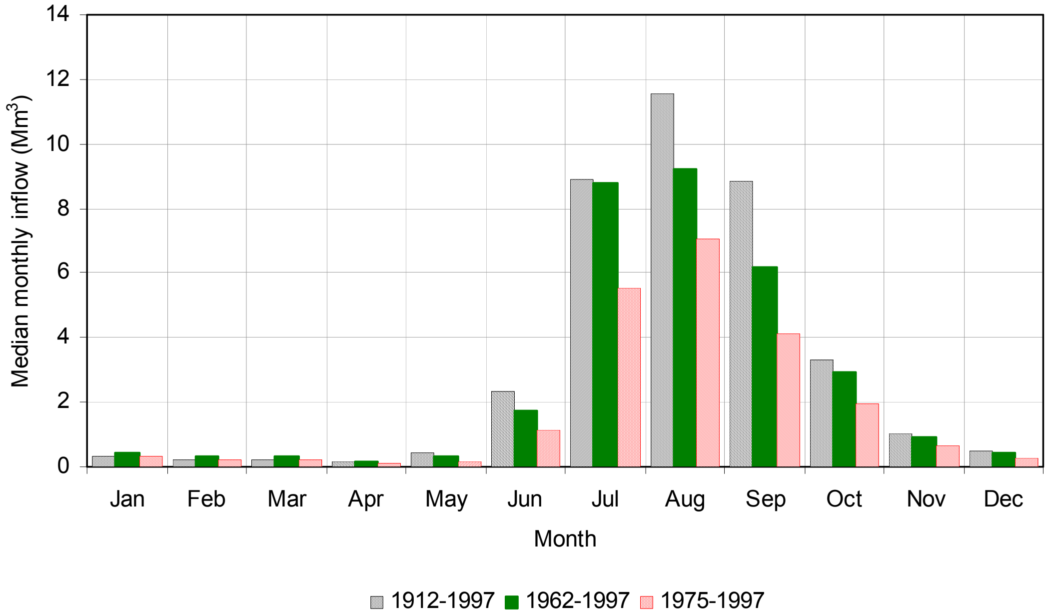

Figure 2: Monthly inflow to Canning Reservoir from 1912-1997

Since 1975 the South-West Land Division of Western Australia, including the Canning catchment, has experienced a decline in rainfall. Mean annual rainfall for the period (1934-1974) was 1226mm compared to 1002 mm for the period 1974-1995 (Canning Dam, S009050), a 18.3% reduction.

As a general rule, the Department of Water's rainfall and surface water discharge modelling indicates that for south-western rivers a reduction of 10% in mean rainfall corresponds to an approximate 30% reduction in stream flow. Within the Canning the current drier conditions have resulted in an estimated 19% and 41% reduction in mean monthly flows for summer and winter months respectively (Storey *et al.*, 2002). Mean monthly discharge data at Seaforth gauging station has reduced from 0.443 m^3/s for the period 1975-2006, to 0.358 m^3/s for the period 1998-2006 (Figure 3), a 19.2% reduction in discharge. Future ecological water requirements will need to account for drier average climatic conditions.

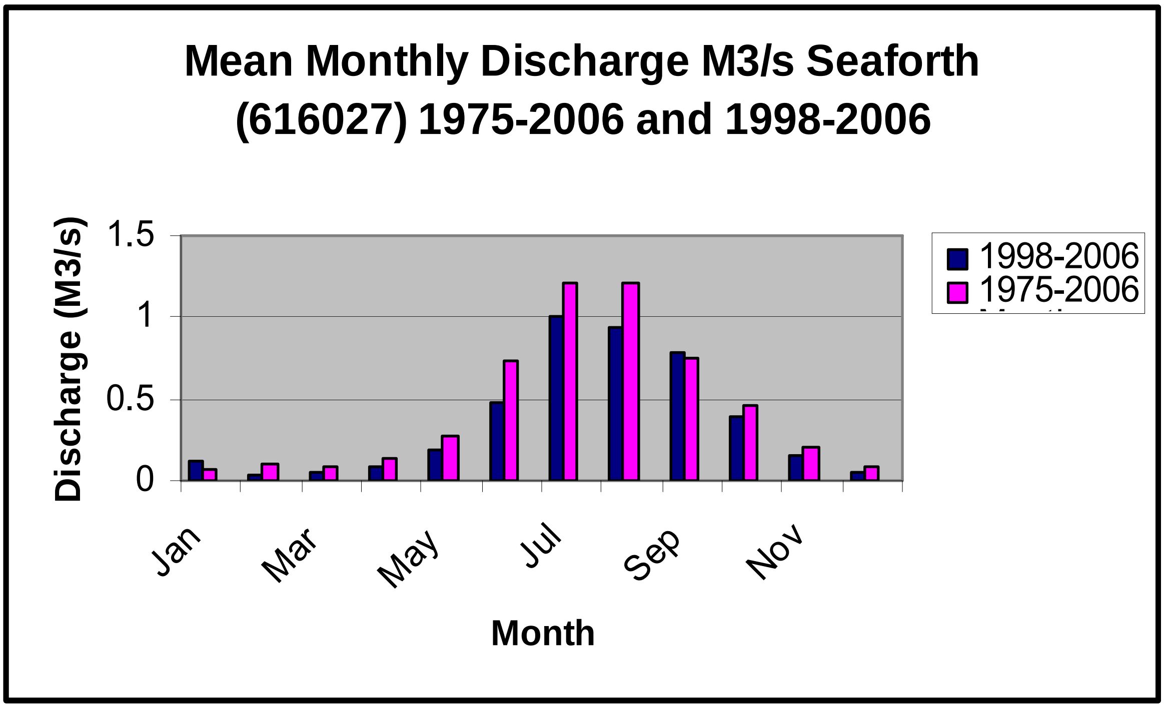

Figure 3: Mean monthly discharge for Seaforth gauging station (616027) 1975-2006 and 1998-2006.

2.3.1 Hydrological impacts of regulation and storage diversion

Public water supply

Flows in the Canning River catchment are impounded by two major water supply dams, (Canning Reservoir and Wungong Reservoir), two smaller dams (Churchman Brook Reservoir and Victoria Reservoir) and numerous smaller weirs and other in-stream structures (Table 1).

The impact of the Canning and Wungong Dams on flows has been very significant. The Canning Dam impounds all incoming flows with limited compensating releases from six sites downstream of the dam (see section 0). Pre-regulation average annual streamflow at the Canning Dam (1908-1934) has been estimated at 57,620 ML/year. Immediately downstream of the dam at the Araluen Pumpback, the first gauging station downstream of the dam, the average annual streamflow has been estimated at 1,165 ML/year (based on a 1935-1995 dataset). This represents a 98% reduction in average annual streamflow below the dam (Storey *et al.* 2002).

Similarly, the Wungong Dam impounds all incoming flows with limited compensating releases from two sites downstream of the dam. Pre-regulation average annual streamflow (1961-1975) at Kargotich Weir has been estimated at 26,958 ML/year. The current estimated average annual streamflow for the Southern-Wungong, not accounting for abstraction from the pipehead dam, is 1718.25 ML/year (Araluen 1977-1995). This equates to a 94% reduction in flows from pre-regulation estimates.

Table 1. Sub-catchments of the Canning River, their characteristics and degree of regulation.

Name	System	Constructed	Catchment Area	Capacity	Abstraction	Comments
Canning	Canning River	1940	804 km^2	93.4 GL	37700ML	Major water source to metropolitan region
Wungong	Wungong Brook/ Southern River	1979	132 km^2	60 GL	20600ML	Water supply for metropolitan region
Churchman Brook	Churchman Brook	1929	16 km^2	2.16 GL	3700ML	Major water source to metropolitan region
New Victoria	Munday Brook	1993 (upgraded)	37 km^2	9.5 GL	6000ML	Major water source to metropolitan region
Kangaroo Gully Diversion Channel	Kangaroo Gully	-	54.3 km^2	-	7061ML	Diverts water from Kangaroo Gully which previously fed into Canning River downstream of the dam into the Canning Reservoir
Berriga Drain and Weir	Wungong Brook	mid 1900s	-	-	563ML (i.e.~57% summer release flow for the Wungong River at 988ML, 2000-2006.)	Built to divert flows into the Serpentine catchment to service dairy properties
Bickley Pumpback	Bickley Brook	1976	-	~100 ML	-	Operating mainly in winter months to pump water back into New Victoria Dam
Araluen Pumpback	Canning River	-	-	1200ML	-	Operating mainly in winter months to pump water back into Canning Dam

Riparian Releases

Following the construction of the Canning and Wungong dams, release points were established along the Canning River and Southern-Wungong River system to provide water to licensed water users and landholders with riparian rights. Six release points along the Canning River: Araluen, Gardens, Hill 60, Bernard Road, Orlando Street, Manning Avenue and Gosnells Bridge; and two points on the Southern-Wungong River at South-west Highway and Darling Range Regional Park (Kargotich) were established (Figure 4). The points release scheme water via modified scour valves into the Canning River. The process of remodelling these release points began in the 1990s after they were re-designated ‘environmental release points’.

Private abstraction

Managing licensed surface water abstraction and the supply of ‘compensating releases’ from the Water Corporation’s environmental release points is the responsibility of the Department of Water. Licensees are allocated a maximum water entitlement (licenced allocation) according to landuse type and area under management. Releases have historically supplied licensed water users with a consistent water supply during the dry summer period. Currently, the average annual licensed water use for the Canning River, from immediately below the dam to Kent Street weir, is 780 ML. The average water release allocation for the Canning River is 896 ML per annum (2000 to 2006). (Table 2)

Table 2. Licensed Water User Type and maximum permissible abstraction volumes per annum (2003-2005).

Category Water Use	Usage Allocated Area (ha)	Usage Allocated Area (%)	Usage Allocated (kL/year)	Usage Allocated Quantity (%)
AGRICULTURAL	66.54	71.94	610,225	78.237
GARDENS	15.10	16.326	86,500	11.090
PARKS AND RECREATION	10.85	11.731	81,000	10.385
DOMESTIC + RURAL	0.00	0.000	2,242	0.287
Total	92	100	779,967	100.000

Licensed water allocation for economic use during the dry spring-summer period represents 78% of the total compensation releases for the Canning River system. The remaining 22% is intended to support a combination of mixed use riparian water rights and flows for environmental processes.

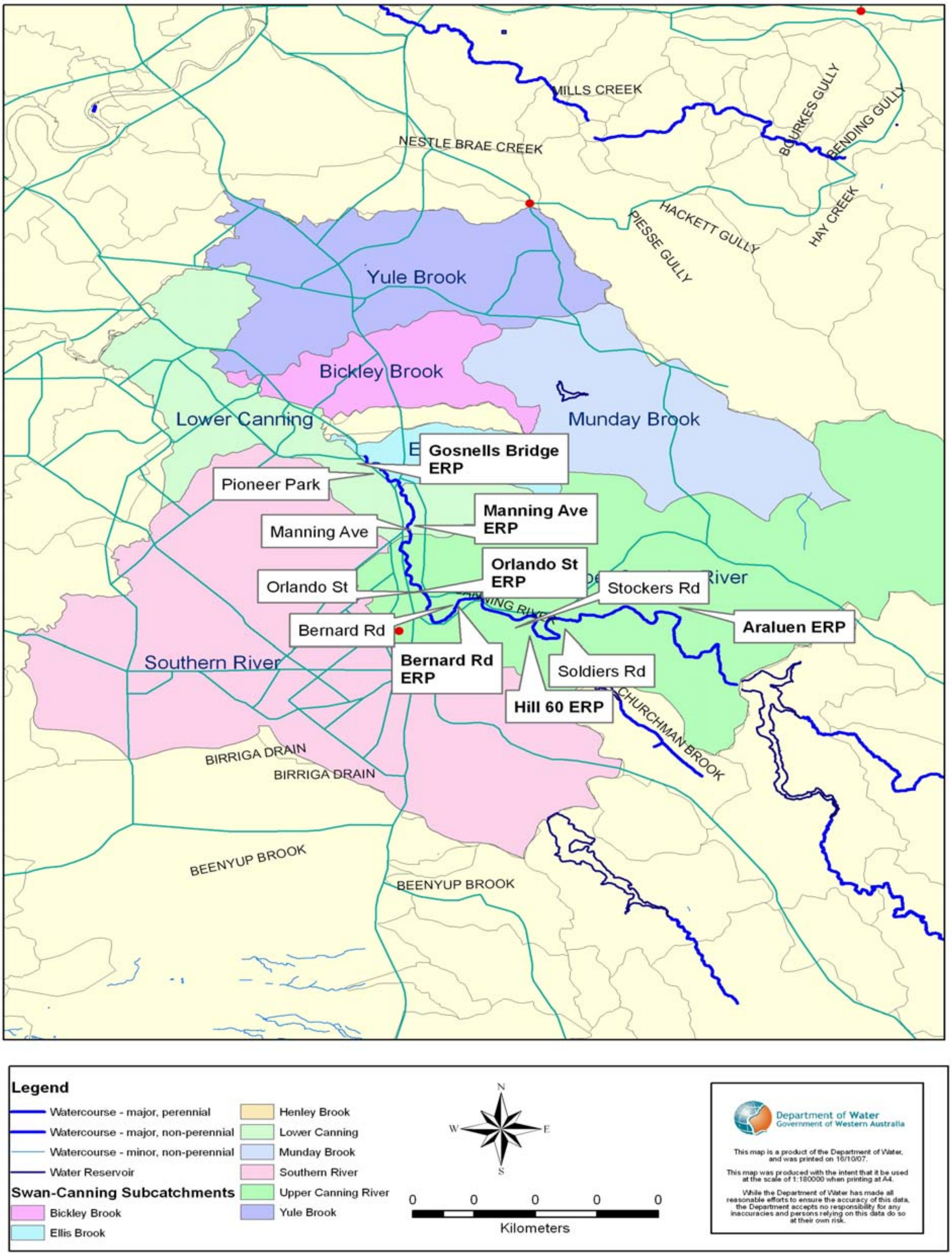

Figure 4: Environmental flow monitoring and environmental water release points on the Canning River system

2.4 Ecological and hydrological monitoring sites

Flow data has been measured at the Seaforth gauging station (616072) since 1974. This data provides the baseline hydrological information for the Canning River. In

2004 additional hydrological monitoring sites were established within six management reaches of the Canning River to provide a better understanding of the flow regime (Figure 4).

Ecological monitoring sites were established at locations along the Canning River and major tributaries in the 1980s and 1990s. Monitoring of macro-invertebrates, fish fauna and physical and chemical water quality parameters have occurred at various times since their inception.

3 Environmental attributes

3.1 Hydrological state and channel geomorphology

Pre-regulation channel dynamics

Prior to the construction of the Canning Dam, the geomorphology and channel dynamics of the river below the dam were dominated by the occurrence of large flood events (Storey *et al.,* 2002). A strong variation in seasonal spring-summer and winter flow regimes existed, with dry summer periods of low perennial flows and wet winter periods dominated by high channel forming flows, providing inundation of the lower floodplain during flood events. As the coastal plain is dominated by highly mobile alluvial sands, the overall channel morphology and sediment regime were dominated by large flow events with the power to mobilise sand beds and flush the river channel.

Current channel and floodplain geomorphology

Below the Canning Dam, the river exhibits a gently meandering planform. On the Darling Scarp the channel is bedrock controlled with a narrow, small amplitude, gentle meander. It is fed in part by the tributaries of Stinton Creek, lower-Churchmans Brook and Stony Brook.

On the Swan Coastal Plain the channel is typified by larger amplitude and wider meanders. The floodplain of the lower Canning River also exhibits differences, in terms of its sedimentology, between the upper and lower reaches. The lower reaches are dominated by active deposition of sediment with most pre impoundment pools now dominated by sand and organic sediment.

Impact of impoundment and catchment management

The hydrology and subsequently the geomorphology of the Canning River have been altered as a result of regulation and altered landuse within the catchment.

Regulation has affected the maximum median monthly discharge ‘peak flows’ recorded. The frequency of important ‘channel-forming’ or bankfull high winter flows has also been reduced.

Catchment clearing and urbanisation on the Swan Coastal Plain have increased the proportion of rainfall that flows as runoff into the river and its tributaries and increased the speed with which the runoff reaches the river. This has altered the system’s hydrology, particularly during floods, from relatively slow, flat response flows (taking a day for a flood peak to develop) to typically very rapid response flows (floods peaking in several hours following rainfall).

Sediment dynamics and loads have also been affected. With the construction of the Canning Dam, the contribution of sediment from the upper catchment was removed. However, the contribution of sediment to the system downstream of the dam has been increased as a result of land clearing for agricultural use and urban development. The contributions from unregulated tributaries and drains downstream of the dam have therefore increased in relative importance.

Flow related issues and considerations

The changes in hydrology and sediment dynamics have caused a shift in channel geo-morphological processes.

Changes in flow responses to rainfall events (i.e. more rapid runoff into the channel and flashier flows), has resulted in widespread channel erosion and incision and overall degradation of the river (Storey *et al*., 2002). In the upper reaches, incision is often bedrock contained. However, channel widening, undercutting and localised bank erosion has occurred.

On the coastal plain sedimentation and channel incision and widening have altered hydraulic geometry at a reach scale. The following changes are evident:

- the lower river has become more incised in its traditional floodplain;
- sediment contribution has altered channel dynamics; and
- large volumes of sediment are stored in channel pools often in association with aquatic and invasive plant species.

The role of in-channel vegetation in sediment and channel dynamics has become a significant management issue. Sediment is deposited as a result of decreased flow magnitude and power, enabling increased colonisation of sediment banks by vegetation, which in turn decreases flow velocities resulting in further deposition of sediment which can then be colonised by more vegetation. This response is evident in the once popular swimming pools at Pioneer Park, Manning Avenue, Orlando Street and Bernard Street. These pools now have a semi-stabilised sediment bed of between 300-750mm in depth which is often colonised by Ribbon weed (*Vallisneria americana*) and frequently fringed by Giant Reed *(Arundo donax).* This results in localised ‘choking’ of the channel and the creation of a raised ‘semi-permanent’ bed.

In order to be geo-morphologically effective (i.e. to mobilise sediment), flows need to be of sufficient magnitude and duration to exceed intrinsic thresholds that limit change.

Recent peak flow ‘bank-full’ events of 16.5m^3/s, during winter 2003, and 11.6m^3/s during autumn (WRL, 2007) were not effective in removing established sediment beds at any of the above mentioned sites. More moderate flows that apply a significant force within the channel over a long period may be more effective (Croot, 2002). Flows with velocities greater than 20-30 cm/s are likely to be required to mobilise the fine to course grain sand sediment (WRM, 2002).

The overall reduction in the magnitude of flows, exacerbated by declining rainfall, has meant that the historic river channel is too big for the current flow regime. The Canning River is still adjusting to changes in flow regime and catchment land uses. Whilst large flows, which fill the historic channel do occur, these no longer represent bankfull flows in the geo-morphological sense. Bankfull flows are defined as the flow rate when the main channel is full and just before the river is in flood (Muirden *et al*., 2003). In natural systems in the south west of Western Australia bankfull flows usually occur once every one to two years. The decreased frequency of bankfull flows combined with incision and erosion of the channel, particularly in Swan Coastal Plain reaches has meant that:

- the size of flows required to fill the channel may have increased;
- channel forming processes have altered; and
- the portion of the channel that regularly influences and is influenced by flows has declined, that is, the 'active' channel has reduced in size.

combined with incision and erosion of the channel, particularly in Swan Coastal Plain reaches has meant that:

To be consistent with the identified desired future state for the Canning River, the objective of an environmental flow program should not be to restore the frequency of bankfull flows for the historic channel. Rather, the objective should be to provide adequate frequency of bankfull flows for the active channel.

In order to arrive at an equilibrium state for the coastal plain planform, flow events need to be of an appropriate magnitude, frequency, and duration to exceed existing threshold conditions provided by a heavily modified flood-pulse response within the lower catchment. It is important to make some effort to maximise the power of these events, to at least, reset emergent vegetation beds without contributing to increased bank erosion.

Flow objectives

- Sufficient flows to scour pools, flow velocities of 20-30 cm/sec, to remove accumulated sediments and organic material (algal mats).
- Sufficient flows to maintain the shape of the active channel.

3.2 Macro-invertebrates

Macro-invertebrates play a major role in the ecology of river systems. They form a vital link in food webs providing a major energy source for higher order aquatic and terrestrial fauna such as fish and waterbirds. Due to their sensitivity to chemical and physical conditions, many species of macro-invertebrates are also important indicators of waterbody health (WRC, 2001).

Assemblages

Macro-invertebrate community structure in river systems is influenced by a number of parameters including substrate composition, water temperature, water chemistry, aquatic and riparian vegetation composition, food availability and biotic interactions (ARL, 1989). Flow regime is an overriding influence on many of these parameters and is therefore an important factor in macro-invertebrate community structure. Studies of southwest rivers including the Canning River have found two main aspects of flow regimes that influence invertebrate community structure: seasonality and predictability.

Seasonality

Unlike many stream systems in eastern Australia, fauna in streams of the south-west of Australia show a marked seasonality which is associated with seasonal changes in the physiochemical environment (Bunn *et al*., 1986). Low flows in summer are associated with warm water, lower dissolved oxygen, increased salt concentration and, in some cases, lower pH (Bunn *et al*., 1986). These conditions are reversed in winter. Bunn *et al*. (1986) identified distinct summer and winter faunas with a relatively rapid transition period at the onset of winter rains and a more gradual return at the start of summer. Stream discharge appeared to be a determining factor of macro-invertebrate communities in streams of the northern jarrah forest (Bunn *et al.,* 1986). The macro-invertebrate community structure in the Canning and Southern-Wungong Rivers also displayed a marked seasonality.

Predictability

Many macro-invertebrate life cycles are intrinsically linked to the predictable low summer flow and high winter flow typical of south-west river systems. Many species having lifecycle stages triggered to coincide with stable flow periods (Bunn, 1988, Storey *et al*., 1999). Continuation of a flow regime with these features, which is often a characteristic of lowland rivers, therefore becomes a critical factor in maintaining macro-invertebrate community structure.

Maintenance of a suitable minimum flow is also critical. Distinct macro-invertebrate community structures exist for intermittent streams compared to permanent streams (ARL, 1989a). Failure to maintain a suitable minimum flow in a typically permanent system can be particularly problematic for species adapted to permanent systems and result in desiccation, de-oxygenation of the water column and accumulation of leaf leachate. Similarly the continuation of the seasonal regime in intermittent streams is important for maintaining the abundance and species richness of particular invertebrates.

Distribution of macro-invertebrates

Repeated monitoring of macroinvertebrate community structure was conducted by the Aquatic Research Laboratory of the University of Western Australia during the 1980's and 1990's (ARL 1984-1987, ARL 1988, ARL 1990 and Storey, 1999). These studies have provided an understanding of the distribution of macro-invertebrates in the Canning River and its major tributaries. Results of monitoring demonstrated the following key points:

- A distinct separation of upland and lowland macro-invertebrate community structure (ARL, 1988f). This was attributed primarily to the permanence of streamflow in lowland sites compared to intermittent streamflow in upland sites. However, the transition from the Darling Scarp to the Swan Coastal Plain also corresponds with changes in velocity, substrate composition and related parameters which also influence community composition.

- The macro-invertebrate community structure of the reach between the Canning Dam and Stinton Creek (approx 5 km) consists of a greater number of taxa than expected and the presence of taxa more typical of a lowland river system (Storey *et al*., 1991). The presence of lowland species was attributed to the predominance of large pools with snags, accumulations of organic and inorganic material and the lack of fast flowing riffle sections (ARL, 1988).

- Habitat diversity is a key component influencing macro-invertebrate taxa diversity. Many species are essentially restricted to particular habitats (WRM, 2005). A large number of macro-invertebrates are associated with complex habitats such as riffles, snags, under rocks and within marginal or trailing vegetation (WRM, 2005; WRC, 2000c).

Impact of impoundment and catchment management

The macro-invertebrate fauna of the Canning River has been impacted by a number of factors including impoundment, land clearing, land use, stream bank disturbance and weed invasion. Increased turbidity, nutrient and pesticide levels in inflows from surrounding urban and rural parts of the catchment have lead to a decline in water quality. There is an increased risk of stratification and anoxia in pools during summer as a result of decreased flows, increased nutrients and resultant increased biological oxygen demand. In many reaches of the river habitat diversity has been reduced as a result of increased erosion and pool aggradation (infilling); themselves a result of altered catchment characteristics (WRM, 2000).

Water quantity

Impoundment by the Canning Dam has resulted in significantly reduced flows in the Canning River, essentially removing or disconnecting the system from its headwaters (Section 4). In the upper reaches, this has altered patterns of macro-invertebrate species distribution. For example, surveys of reaches upstream of the confluence of Stinton Creek demonstrated that the macro-invertebrate community structure more closely resembled that typical of lowland reaches. The predominance of species typical of a lowland reach was directly attributed to the impact of impoundment due to the absence of flushing by winter spates, leading to the development of a section of river typical of a mature river in a downstream location (ARL, 1988d).

In comparison, the macro-invertebrate community structure present in the reach below Stinton Creek tended to be indicative of an upland system with faster flowing water, riffle sections and increased sediment carrying capacity (ARL, 1988d). The inputs from a major tributary, Stinton Creek, increased the discharge and spates in this section of the Canning River, returning the physical conditions and regime to that more typical of a mid-order stream on the Darling Scarp. This results in a ‘reset’ of the macro-invertebrate community structure.

Reduced flows also impact on community structure and health during summer when sections of the river are reduced to a series of slow flowing or stagnant pools. Macro-invertebrates are at risk of desiccation during the dry season when adequate flows are not maintained (WRM, 2000). This is exacerbated by the presence of various weirs and man-made controls which separate sections of the river. Water quantity also has significant implications for water quality. This is particularly relevant during summer low flows.

Water quality

Macro-invertebrate communities of the Canning River are influenced by a range of water quality parameters including: dissolved oxygen concentration, turbidity, sedimentation, nutrient concentrations and pollution by chemicals such as pesticides. For example, low species diversity and altered species abundance are often features of macro-invertebrate communities affected by agricultural pollution (ARL, 1988d). Dissolved oxygen concentration is a critical water quality parameter, particularly during summer. Low flows significantly increase the risk of stratification and anoxia in slow flowing or stagnant pools. Although tolerances of macro-invertebrate species to low levels of dissolved oxygen differ, levels of dissolved oxygen below 2mg/L are considered likely to result in reduced health and possible death of aquatic fauna (WRM, 2005).

The quality of water releases is also an important consideration in designing an artificially maintained flow regime. Currently environmental water releases are sourced from existing Water Corporation release points, via scheme water mains. The scheme water is chlorinated and there were concerns that chlorine was having an adverse impact on aquatic fauna in the river system. In freshwater systems a trigger value of 0.4μg/L chlorine protects 99% of species, 3μg/L chlorine protects 95% of species, 6μg/L chlorine protects 90% of species and 13μg/L chlorine protects 80% of species (*Australian and New Zealand Guidelines for Fresh and Marine Water Quality, ANZECC* 2000).

The Department, with assistance from Curtin University students, undertook an ecological study to determine the levels of chlorine and what effects, if any, chlorine has on the macro -invertebrate communities. Chlorine concentrations at two locations, Orlando Street (Canning River) and upstream South Western highway (Wungong River) were identified as exceeding the recommended ANZECC 2000 levels. The average total chlorine concentration across Orlando Street sample sites was 56 μg/L, at a release discharge of approximately 2.0 ML/day. At upstream South Western highway (Wungong River), average total chlorine concentration across the sampling sites was 172μg/L, at a release discharge of approximately 2.0 ML/day. At low concentrations there is limited evidence to suggest that chlorine has an adverse effect on macro-invertebrate communities. However, when present in large concentrations as at Wungong (Figure 5) and Orlando Street (Figure 6), chlorine appeared to adversely affect the number of taxa inhabiting the area.

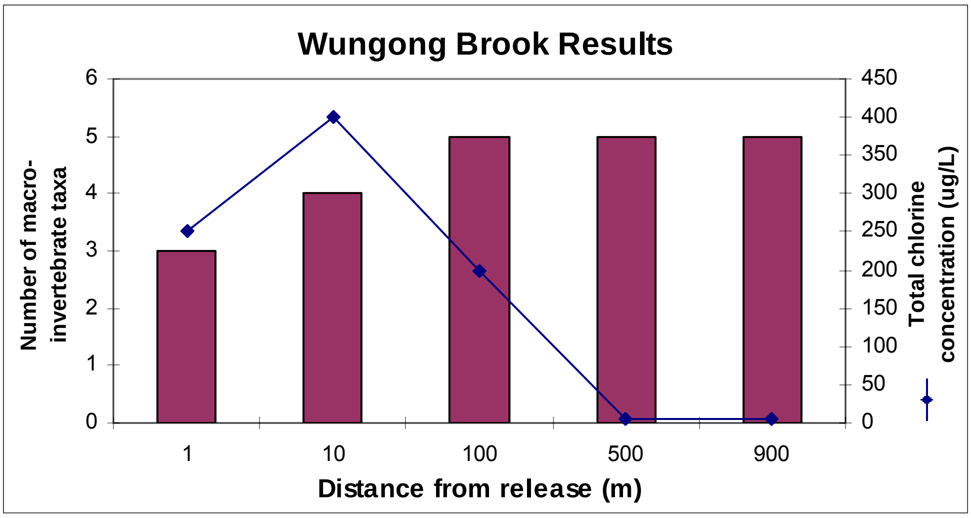

Figure 5: Number of macro-invertebrate taxa and total chlorine concentration at incremental distances from the Wungong environmental release point

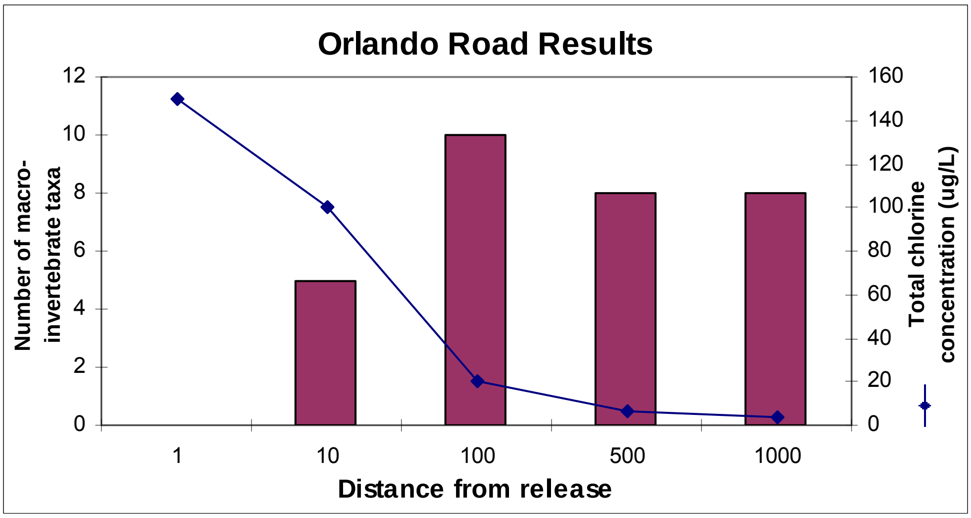

Figure 6: Number of macro-invertebrate taxa and total chlorine concentration at incremental distances from the Orlando Street environmental release point

Ensuring the breakdown of chlorine is essential in areas such as the Wungong where chlorinated water exceeds the ANZECC 2000 guidelines.

Chlorinated water is the only source of water in the river during the summer months. Modification or replacement of the existing release points to facilitate aeration and sunlight penetration which act to break down chlorine in water, may prove beneficial in meeting recommended chlorine concentrations (Reid *et al.*, 2005).

Habitat diversity

Habitat diversity is an important influence on macro-invertebrate species richness and community structure. The 2000 ecological monitoring of the Canning and Southern

Wungong rivers found that sites with the greatest macro-invertebrate species richness tended to be those with the greatest habitat diversity (WRM, 2000). Components of habitat that appeared to be important were: relatively undisturbed bushland; pool and riffle sequence; emergent and trailing vegetation; submerged macrophytes; and large woody debris. Riffle habitat was considered highly productive for macro-invertebrates and maintains high biodiversity (Storey, 2002).

Sites lacking habitat diversity such as those that had effectively been channelised and were straight and shallow, had uniform substrate and/or minimal riparian vegetation had low species diversity (WRM, 2000). The reduced habitat diversity in streams on the Swan Coastal Plain can be primarily attributed to altered land use, in particular, land clearing, bank degradation due to stock access, weeds, and removal of large woody debris for 'flood management'. Impoundment by the Canning Dam compounds this problem due to the lack of flushing flows. A study on erosion and aggradation in the Canning River system determined that substantial in-filling of pools was occurring in the Canning System, particularly in the lower reaches (WRM, 2000). Historically, sediments that settled in pools over summer would be flushed downstream by winter flows, maintaining channel morphology and pool depth. Presently, altered hydrology and bank vegetation has increased erosion and the transported material is deposited in pools (WRM, 2000). This in-filling has resulted in the loss of important aquatic habitat and functionality and in turn influenced both macro-invertebrate and fish diversity (see section 4.3) (WRM, 2000). Many pools are no longer suitable for summer refuge for macro-invertebrates (and fish and waterbirds).

Macro-invertebrate community structure

Physical conditions have a marked impact on macro-invertebrate community structure. Analysis of post impoundment flow data from Stinton Creek gauging station indicated that the Creek increased the mean annual discharge of the lower Canning River by approximately 260% (i.e. compared with that portion of the lower Canning upstream of the confluence with Stinton Creek). The increased discharge and spates correlated with increased flow velocity (particularly in winter), increased depth, dissolved oxygen at >100% saturation and reduced organic particulate matter in the reach below Stinton Creek compared with the reaches above (Storey *et al*., 1991). This resetting of conditions indicates that natural recovery of both the physical conditions and macro-invertebrate community structure can be achieved via inputs from major tributaries, or where this is not possible, from compensatory releases (Storey *et al.,* 1991).

Flow related issues and considerations

Maintenance of the macro-invertebrate community structure is dependent on predictable and seasonal flow events. A flow regime that reflects the attributes that are typical of a river in this location is important to ensure the maintenance of the macro-invertebrate community structure. Life histories of macro-invertebrates are fundamentally linked to predictable and seasonal flows with low flow events having a more pronounced effect than high flow events (WRM, 2005). Summer/spring spawning is a common life history characteristic of many aquatic macro-invertebrates

(WRM, 2005). Historically, the reaches of the Canning River covered by this study were a permanent system. It is therefore important to ensure that the presence of permanent freshwater is maintained to support breeding and recruitment of macro-invertebrates (WRM, 2005). Determination of a minimum stage height required in summer to prevent anoxia, maintain connectivity and prevent desiccation will assist in the protection of macro-invertebrates during the dry season. The Canning River is sectioned by a series of control points such as weirs and riffle sections (rock runs).

Diversity of habitat is important to ensure the maintenance of macro-invertebrate community structure (WRM, 2005). Sufficient flows need to be maintained to ensure that snags, rocks, benches, macrophytes and trailing vegetation are inundated. Secondary channels, shallow floodplain areas and backwaters provide refuge habitat from winter spates and additional potential foraging areas for both macro-invertebrates and fish (Section 4.3). In many cases modification to the river bank and riparian zone and the significant reduction of flows reaching the Canning River has resulted in many potential habitats being unreachable, even during winter flows. Where floodplain and backwaters are accessible to the active channel, restoration activities and flow releases in winter should aim to restore connection to these areas.

Riffle habitat is considered to be highly productive for macro-invertebrates and maintains high biodiversity (Storey, 2002). Macro-invertebrates associated with riffles depend on constant flow to provide food and oxygen. It is therefore important to maintain coverage of riffles to maintain diversity (WRM, 2005). A water depth of 5cm over 50% of riffle zones is regarded as the minimum necessary to support benthic invertebrate communities in summer (Storey, 2002). Some restoration works have been undertaken on the Canning River to reintroduce riffle habitat into sections of the river channel that have been highly degraded. The placement of logs and rocks has been designed to increase habitat diversity and assist in the deepening of pools. Planting of marginal reeds and rushes has also occurred and in time will provide shade and habitat for macro-invertebrates and native fish. The provision of flows to maximise the benefit of instream habitat restoration is imperative to the ecology of the Canning River system.

Flow objectives

- Maintain a minimum height of 5-10cm over gravel runs and riffles as biodiversity 'hotspots' for macro-invertebrates.
- Flows to maintain submerged macrophyte beds as habitat for macro-invertebrates.
- Sufficient stage height to ensure marginal reeds/rushes are trailing and providing habitat for macro-invertebrates.
- Maintain overbank flows to inundate the floodplain and provide shallow floodplain and backwater areas for habitat and avoidance of high flows.
- Flows to maintain connectivity of pools in summer.
- Flows to prevent significant stratification or anoxia in pools during summer.

- Flows (considering seasonality and predictability) to maintain macro-invertebrate community structure typical of reach location.

3.3 Fish fauna

Compared to elsewhere in Australia fish fauna in freshwater systems of the southwest are relatively depauperate in terms of species diversity and also display a high degree of endemism (Storey *et al*., 2002 and Morgan *et al.*, 2007). The fish fauna of the Canning River is comprised of 12 species (ARL 1988b,c,d; Davies *et al*., 1998 a,b; Morgan *et al*., 2007; Pusey *et al*., 1989; Storey *et al*.,1998; 2002; Strategen, 2004; Morgan and Beatty 2002) including:

- four native freshwater fishes (endemic to the south-western Australia) - the freshwater cobbler (*Tandanus bostocki*), western minnow (*Galaxias occidentalis*), western pygmy perch (*Edelia vittata*) and the nightfish (*Bostockia porosa*).
- three fishes that are generally considered estuarine species - the western hardyhead (*Leptatherina wallacei*), south-west goby (*Afurcagobius suppositus*), and the Sea Mullet (*Mugil cephalus*); and
- four introduced species; the one-spot livebearer (*Phalloceros caudimaculatus*), eastern mosquitofish (*Gambusia holbrooki*), goldfish (*Carassius auratus*) and the rainbow trout (*Oncorhynchus mykiss*).

With the exception of the introduced species, it was suggested that the current diversity of fish species of the Canning River system is likely to be unchanged since European settlement (Morgan *et al*., 2007).

Generally, all native species encountered are widely distributed throughout the south-west of Western Australia and therefore cannot be considered threatened on a regional basis. However, species such as the western minnow and pygmy perch may be considered locally threatened because of their absence from sites (Storey *et al*., 2002).

Species requirements and spawning characteristics

The habitat requirements and spawning characteristics of species recorded within the study area are summarised in Table 3. More detailed information on each species can be found in Appendix A. Of the four native freshwater fishes, the freshwater cobbler and nightfish are essentially restricted to the main channel of the Canning River and Wungong Reservoir. The western minnow and western pygmy perch are more widespread being found within both the tributaries and main channel (Morgan *et al*., 2007; Storey *et al*., 1990,1991,2002).

Table 3: Summary of freshwater fish species habitat requirements

Species	**Habitat Requirements**	**Spawning**	**Spawning Habitat**
Western minnow (*Galaxias occidentalis*)	Fast flowing water near rapids and waterfalls and slower moving streams and pools around submerged vegetation and woody debris	Migrates to tributaries to spawn between June and September – peak in August.	Flooded vegetation in tributaries.
Western pygmy perch	Associated with riparian vegetation or cover such as	Spawns between July and November –	Floodwaters of main river, small

Species	Habitat Requirements	Spawning	Spawning Habitat
(*Edelia vittata*)	macrophytes and algae. Rarely in open or deep water.	peak in September and October	side creeks and flooded stream sides.
Nightfish (*Bostockia porosa*)	Shelters under ledges, rocks, logs and inundated vegetation. Only found in open pools when water level receded. Mainly active at night.	After winter rains – Between (August and November)	Flooded tributaries with inundated vegetation and fast-flowing water.
Freshwater cobbler (*Tandanas bostocki*)	Slow moving streams, isolated pools in riverbeds, reservoirs. Swims close to rocky, gravelly or sandy bottoms, underwater cavities in riverbanks and root mounds of sedge tussocks utilised for shelter.	Between spring and mid-summer (November-January) when temperatures rise between 20-24 ºC	Build a 'nest' snagged under submerged rocks or woody debris. Protected by the males.
Swan River Goby (*Pseudogobius olorum*)	On mud or rock bottoms of freshwater rivers and ponds and brackish esuaries.	During spring	Upper reaches of estuaries (<30% salinity) where aquatic vegetation is plentiful.
Big headed goby/South-western Goby (*Afurcagobius suppositus*)	Rests on silt or mud bottoms in quiet waters of brackish estuaries or coastal lakes and lower reaches of freshwater streams.	*Not identified*	*Not identified*
Swan River hardyhead/Western Hardyhead (*Leptatherina wallacei*)	Swims near the surface near woody debris and aquatic plants in upper estuarine reaches and flowing freshwater streams	Extended period - Spring to summer and dies shortly after spawning	No specific habitat determined, possibly a wide range of habitats utilised.
Mosquitofish (*Gambusia holbrooki*)	Warm still waters. Typically seen shoaling at the edges of streams and lakes.	Livebearers in spring, summer and autumn when water temp >15-16ºC	No specific habitat
Rainbow trout (*Oncorhynchus mykiss*)	Prefers lakes but inhabits streams in cool (10-22ºC), well oxygenated water typically over gravelly bottoms.	Limited natural spawning.	Stocks artificially maintained in lakes and reservoirs.
Brown trout (*Salmo trutta*)	Cool flowing streams (below 25ºC).	During winter	Areas with gravel substrate
One-spot livebearer/Speckled Mosquitofish (*Phalloceros caudimaculatus*)	Swamps and drains of Perth metropolitan area	Spring, summer, and autumn.	Rivers, ponds, drains.
Goldfish/Carp (*Crassius auratus*)	Still or slow flowing waters. Able to withstand high temperatures and low oxygen	*Not identified*	Quiet backwaters of rivers, swamps and lakes.

The information within this table was collated from Allen et al.*, (2002); Morgan* et al.*, (1996); Pen and Potter (1990a); Pen and Potter (1990b). * denotes introduced species*

Storey (1998) compared the physio-chemical and habitat parameters to the number of species of fish at sites in the Canning River to determine whether relationships existed between fish and habitat. The following relationships were observed:

1. Sites with a high cover of both cobbles and boulders had a greater abundance of western pygmy perch than sites with a low cover.

2. Sites with extensive riparian cover and a wide buffer of riparian vegetation have a greater number of western minnow than sites with little cover and a narrow vegetation buffer.

3. Sites with a high cover of boulders have a greater number of Nightfish than sites with a low cover.

The most significant relationships observed in the survey were between species richness and a) the extent of riparian cover and b) the width of vegetation buffer strip at a site. The results suggested that by increasing the width of the vegetated buffer and the extent of riparian cover, species richness at a site may be increased (Storey, 1998).

However, Storey (1998) also suggested that the extent of riparian cover and width of the vegetated buffer zone may not directly affect species richness but rather, it may have affected other parameters to which fish respond. For instance, higher dissolved oxygen and water temperature was observed at sites with little riparian cover. The width of the vegetation buffer was also correlated with the levels of organic material (a food source), emergent and submerged macrophytes (habitat for spawning and cover from predators), and temperature.

Submerged macrophytes may be important in providing habitat for feeding, spawning and predator avoidance for fish species in the Canning River. Within the Canning River, macrophytes occur within pools at Bernard Street, Manning Avenue, Orlando Street, Pioneer Park and Kent Street Weir. Macrophytes are also important spawning habitat and for predator-avoidance for small species and provide an important substrate for algal production.

Fish recruitment and migration

Each of the native freshwater fishes that are found within the Canning River migrate to some extent and generally at different times of the year (Morgan *et al.,* 2007). Migrations are not restricted to breeding nor are they upstream only, but may be for feeding, or as juveniles migrating downstream to recruit into an area.

The western minnow moves upstream into tributaries to spawn on flooded vegetation between June and late September (Storey *et al*., 2002). The nightfish migration occurs in late August to early September, while the western pygmy perch migrates from September to mid October. In contrast to other species in the Canning River, the freshwater cobbler spawns in late spring through summer (Morgan *et al*., 2007).

As well as the flooding of vegetation, fast flowing waters in tributary streams also appears to be an important 'stimulus' for successful spawning (e.g. the western minnow; Pen and Potter 1991 b and Storey *et al*., 2002).

Impacts of impoundment and catchment management

Whilst it appears that fish species diversity in the Canning River has not changed since regulation of the river system, fish abundance has been significantly influenced (Storey *et al*., 2002, Morgan *et al*., 2007).

It is suggested that the decline in natural flow has altered pool depth, velocity, pool replenishment rates and river substrate structure, resulting in:

- the loss of wetland habitats and the connection between the main channel and off-channel wetland habitats; and
- eutrophication and degraded water quality.

In addition, the introduction of exotic fish species (and associated parasites), the number of impediments, subsequent modification of habitat through riparian vegetation clearing and in-channel de-snagging is likely to have altered the degree to which each species contributes to the faunal composition of the system (Morgan *et al*., 2007).

In-channel habitat features such as bank undercuts, root mats and crayfish burrows provide areas for predator avoidance for the western pygmy-perch and nightfish (Storey *et al*., 2004).

Fish migration

Impoundment of flow by constructed weirs along the Canning River is considered to have had a significant impact upon fish migration and spawning.

There are presently eight recorded impoundments between Kent Street Weir and the base of Canning Dam; one crump-type weir (Seaforth 616027), two v-notch weirs (Mackenzie Grove and Araluen), and five known private weirs located upstream, and one downstream of Seaforth Gauging Station. These structures are considered to represent, to varying degrees, barriers to fish migration (Storey *et al*., 2002; Morgan *et al*., 2007), although the migration of the western minnow does not appear to be affected by Crump-type weirs (ARL, 1990a). (The Crump-type weir is designed to be seasonally submerged during higher flow periods to allow upstream fish migration.) At Seaforth weir, fish passage was recorded (June to September) for the western minnow, nightfish, and pygmy perch at depths of 0.18 to 0.36m (over the weir) and a velocity of 0-0.50 cm/s (Morgan *et al*., 2007). The nightfish generally prefers a mean water velocity below 0.29 m/s (Storey *et al*., 2004, cited Thorburn, 1999).

During low flow periods, impediments such as natural rock-riffle gravel runs and recently constructed 'man-made' riffles may provide a barrier to fish passage. Storey *et al*. (2002) recommended that minimum flows of 0.1m from winter and late spring are required to ensure fish migration and recruitment for the western minnow, pygmy perch, and nightfish.

Cobbler migration occurs during late spring to late summer in rivers of south western Australia (Morgan *et al*., 2007). Morgan (2007) recorded cobbler moving over the Seaforth weir at depths >0.2m (AHD) in late November. Monitoring at Seaforth weir found that fish passage for Cobbler was obstructed during the summer period (Morgan *et al*., 2007).

Flow connectivity

For all species in the Canning system, there is a pre-requisite for adequate permanent water. Pusey & Edward (1990) and Pen *et al*. (1993) reported for the Swan region, that temporary streams and tributaries have reduced species richness due to 'restricted' seasonal accessibility and limited food supply for young fish. Although several species invade seasonal creeks to reproduce, none of them have adaptations to withstand desiccation (Storey *et al*., 2002). If water levels fall too soon, or fluctuate greatly, eggs may be left dry. Therefore, it is essential that flows maintain river connectivity, floodplain and off channel spawning habitat, and sufficient flows to allow fish passage over all obstacles where possible. Flow seasonality and connectivity between reaches is required for migration in winter/spring for the western minnow, western pygmy perch, and nightfish. Maintenance of flow at sufficient rates to provide refuge pools for cobbler recruitment, spawning and nesting during summer 'dry periods' is essential (Morgan *et al.,* 2007).

Water quality and river pools

Reduced discharge during summer/autumn and impoundment have the potential to increase the risk of anoxia and fish kills in river pools. Dissolved oxygen concentrations in river pools are controlled by the difference between the supply and the consumption of oxygen in the pool. Atmospheric mixing, aquatic plant photosynthesis and dissolved oxygen in inflows to the pool all contribute to the supply of oxygen to the pool. Oxygen in pools is consumed by respiration of the plants and animals and biological and oxidation processes.

Dissolved oxygen concentrations usually increase during the day and reduce overnight. Reductions tend to be greatest near the base of pools following mild still nights, when warm night-time temperatures and low wind velocities limit mixing. Anoxic conditions can result throughout the water column if conditions persist. Sub-lethal effects on fish (e.g. reduced egg viability) can develop where oxygen levels fall below approximately 2 $mg.L^{-1}$ (Storey *et al*., 2002). Flows that maintain oxygen concentrations greater than 2 $mg.L^{-1}$ in summer pool refuges, at all sites are required during low-flow periods (Late spring to autumn).

Introduced species

The introduced mosquitofish are considered to have a significant competitive and predatory impact on the distribution and abundance of endemic freshwater fish species within the Swan region. High densities of mosquitofish result in a high incidence of fin damage (fin nipping) in native species (Morgan *et al*., 1998; Storey *et al*., 2002). Mosquitofish are typically suited to lentic habitats including lakes, pools and slow flowing rivers. Flow regulation and the absence of large flushing flows in winter in the Canning seems to favour the prevalence of mosquitofish; a relatively poor swimmer. A study by Pusey *et al.* (1988) on the Canning and North Dandalup rivers found that mosquitofish was most abundant in lentic habitats only. Where native fish co-occurred with mosquitofish, they were in low densities and usually confined to inlet streams. Morgan *et al.* (1996) found a similar pattern: in waterbodies where mosquitofish was present, western pygmy perch, western minnow and nightfish were rare or absent. In contrast, rivers and streams where mosquitofish were absent, the same native species were typically abundant. The only waterbody where western pygmy perch was abundant when mosquitofish was present was in a lake containing large amounts of cover in the form of aquatic macrophytes and algae.

Recent monitoring has suggested the one-spot livebearer has a 'competitive advantage' over the mosquitofish. Further investigation is warranted to understand the ecology of the one-spot livebearer, and it's potential impact upon both the mosquitofish and endemic freshwater species in the Canning River system (Morgan *et al.,* 2007)

Modifications to the flow regime of the Canning River have important implications for the dynamics and management of mosquitofish populations. In the southwest river systems regulation by dams and weirs which rarely overflow, has resulted in wide, deep, and slow-flowing lower reaches, creating habitat conditions that suit the mosquitofish (Storey *et al*., 2002). Pusey (1989) noted that natural winter spates in unregulated systems reduced the population density of mosquitofish to low levels, thus permitting coexistence with small indigenous endemic species. The maintenance of winter spates is therefore necessary to restore/maintain natural habitat and reduce the suitability of the system for proliferation of the mosquitofish.

Flow related issues and considerations

Estimates of flow requirements are required:

- to support emergent and submerged macrophytes as these provide a food source and habitat refuge for endemic species;
- to enable species to move over obstacles and into backwaters, tributaries, and drains, particularly seasonal creeks, to spawn on flooded vegetation; and
- to improve water quality.

In particular, predictable winter/spring flooding should be maintained to ensure breeding success and strong recruitment of the western minnow, pygmy perch, and nightfish (Storey *et al*., 2002). These flows should be delivered in pulses to provide sufficient depth to maximise the opportunity for accumulated fish to traverse obstacles and to prevent desiccation of fish eggs. WEC (2002) suggested that flow-pulses be maintained for at least 10 days during each of the months of August and September.

Additional 'sufficient flows' to inundate impoundments for upstream cobbler migration during the summer spawning period (November to February) may be required during traditional low-flow periods (Morgan *et al*., 2007). It is likely, during dry periods, that larger impoundments will remain impassable for upstream movement in the absence of some form of fish passage structure at each of these structures.

Further investigation into the impacts of private and institutional weirs is required given their observed impediment to fish migration (Morgan *et al*., 2007; Storey *et al*., 2002). Where ever possible, unused structures should be decommissioned or fish passage structures constructed to allow complete upstream passage for migratory native species (Storey *et al*., 2002).

The retention of a predictable natural pattern of low summer flows and winter spates may also be beneficial in managing introduced species such as the mosquitofish (Storey *et al*., 2002).

Protection and enhancement of habitat such as existing flooded off-river areas, aquatic vegetation, wetlands, backwaters, drains, and tributaries is essential for the conservation of endemic freshwater species.

Flow objectives

- Water depth to provide fish passage over impoundments for native species during periods of migration.
- Sufficient flows to maintain oxygen levels above 2 $mg.L^{-1}$ to avoid the possibility of fish kills. Pools should not become isolated and flow discharges should be sufficient to maintain replenishment rates to prevent anoxic conditions.
- Sufficient flows to inundate submerged, emergent, fringing and trailing vegetation at >0.1m within the existing channel and off-channel areas for spawning and recruitment of small-bodied freshwater fish species.
- Flow to inundate in-stream benches and inundate emergent vegetation for ‘allochotochous litter transfer’ and as habitat for fish.
- Avoid high flows that may dislodge cobbler 'nests' downstream.
- Flows to maintain flow connectivity and sufficient replenishment rates to avoid anoxic conditions for pools in summer.
- Flows to maintain submerged macrophyte bed habitat for fish.
- Maintain existing pools at a thalweg depth of 0.5-0.8m for cobbler nests of and as refuge habitat for other fish species.
- Maintain shallow backwater areas as nursery, predator avoidance, and habitat areas for juvenile fish. As well areas to avoid high flows in the main channel.
- Flows to inundate undercutting to provide fish habitat for small-bodied fish species
- Provide sufficient water to prevent sediment aggradation to maintain habitat and functionality of pools for fish.
- Maintain overbank flows to inundate and connect floodplain wetlands and shallow-flooded off-river areas (tributaries/drains) for foraging and spawning habitat for native fish.

3.4 Waterbirds

The association of waterbirds with specific waterbodies is often relatively indirect (when compared to fish and macro-invertebrate fauna) as many populations utilise a variety of waterbodies in the region and often only for a limited period. The Canning River system is an important permanent freshwater drought refuge and breeding habitat for waterbird populations (Meagher and LeProvost, 1975; Jaensch, 1987).

Assemblages

Perth's Swan-Canning river system supports a high diversity of waterbirds. The permanence of river pools and the close proximity to more than 120 wetlands in the Perth Metropolitan area are important in maintaining this diversity (Jaensch, 1987). Chambers (1987) found that waterbird species were closely associated with fringing vegetation. Waterbirds, downstream of Kent St Weir, have been observed utilising a range of habitats including open river, ponds and shallow flats, open to closed heath, sedgeland to closed sedgeland and low open woodland (Meagher& LeProvost, 1975). A number of species including herons, egrets and ibis utilise the riparian and fringing vegetation of the Canning River for nesting and foraging for insects, aquatic invertebrates, fish and aquatic vegetation (Chambers, 1987).

Seventy-nine species of waterbird were recorded during a study of waterbird usage of wetlands on the Swan Coastal Plain during 1990 and 1992 (Storey *et al.,* 1993). The twenty most abundant species of waterbird are listed in the table below. The importance of wetlands (including the Swan-Canning River System) on the Swan Coastal Plain in supporting large numbers of waterbirds and acting as a drought refuge was confirmed.

Table 4. Most common waterbird species in the Canning River area (Adapted from Storey et al., 1993)

Rank	Common name
1	Eurasian Coot
2	Grey Teal
3	Pacific Black Duck
4	Silver Gull
5	Australian Shelduck
6	Hoary-headed Grebe
7	Black Swan
8	Black winged Stilt
9	Pink-eared Duck
10	Maned Duck
11	Little Black Cormorant
12	Red-necked Stint
13	Red-necked Avocet
14	Australasian Shoveler
15	Australasian Grebe
16	Straw-necked Ibis
17	Blue-billed duck
18	Dusky Moorhen
19	Musk Duck
20	Little pied Cormorant

Environmental variables with the most influence on waterbird usage were wetland size, water depth, vegetation structure and primary productivity. There was consistently a significant relationship between waterbird usage and the amount of emergent vegetation and diversity of vegetation structure (Storey *et al.,* 1993). The study determined the following broad, generalised relationships between waterbirds and wetland characteristics:

- Vegetation structure was particularly important for nesting birds, with some species requiring inundated vegetation;
- Species richness was higher for permanent wetlands. This was due to the occurrence of waterbird species that were less mobile and tended to be resident in a wetland; and
- Permanent wetlands were important as a drought refuge in summer and autumn.

On a regional scale, winter-wet areas supported more breeding activity than permanent and seasonal wetlands combined and suggested that maintenance of certain common waterbird populations was dependent on the continued existence of winter-wet areas (contains shallow water from mid-winter to late spring and usually on agricultural land).

The occurrences of individual species of waterbird showed the greatest numbers of associations with area, pH, complexity of vegetation structure, water regime (depth and permanence), width of wading zone and salinity.

Storey *et al*. (1993) made the following recommendations for wetland management based on the significant relationships:

- Bigger wetlands and wetlands with complex vegetation and higher primary productivity support more birds;
- Water depth should probably be >1 m at the time of the year when the wetland is fulfilling its primary waterbird function;
- Most species prefer comparatively fresh water;
- The requirements of breeding is less clear but the presence of trees is important for many species, depth should be >0.5 m; and
- Some species prefer wetlands with an abundance of fish.

As a signatory of the Japan-Australia Migratory Birds Agreement (JAMBA Treaty) and the China-Australia Migratory Birds Agreement (CAMBA Treaty) the Government of Australia is required to protect waterbird species listed in these agreements. Of the 87 species identified in a survey of waterbirds in the Swan Canning Estuary, 31 species are listed on the JAMBA Treaty and 28 of these are trans-equatorial migrants (Jaensch, 1987).

Storey and Rippingale (2000) recorded a total of eighteen species and 3306 individuals in four reaches of the Canning River directly upstream of Kent St Weir. Habitat structure tended to be a major factor in the distribution of waterbird species. Open parkland tended to be suited to species such as the Black Duck and Maned Duck while large areas of submerged macrophyte contained high numbers of Australasian Grebe.

Impact of impoundment and catchment management

The fringing vegetation of the rivers is drastically modified from that which existed prior to European settlement. Pen (1993) conducted a survey of the fringing vegetation and found that although most areas had been cleared, large relatively undisturbed areas of winter-wet vegetation remain (Pen, 1993). These areas are important habitat to waterbirds, in particular for breeding (Storey *et al.,* 1993). Due to the extent of clearing on the Swan Coastal Plain and the reduced habitat availability to waterbirds, the few sites remaining that are dependent on river flow, particularly those recognised as providing important waterbird habitat, are of elevated significance.

Flow related issues and considerations

Due to the variability in the distribution of waterbird populations in the study area, the importance of flow to the maintenance of waterbird populations is unclear. Permanent freshwater reaches upstream from Kent Street Weir to the Canning Dam may act as important drought refuges, during periods of low rainfall. Important waterbird habitats have been identified in previous foreshore assessments such as winter-wet areas and remnant riparian vegetation. Baseline ecological data from the Swan River Trust Foreshore Condition Report, once completed, may provide a valuable census of information for species distribution and likely habitats for water birds within the riparian zone.

Flow objectives

- Maintain permanent pools as a summer and drought refuge for waterbirds.
- Maintain flows to protect riparian vegetation, particularly seasonally inundated vegetation that may provide breeding habitat.
- Maintain adequate flow to protect key habitat sites.

3.5 Water quality parameters

Impoundment of the Canning River and clearing and altered land use in the Canning Catchment since European settlement has changed the water quality in the system. Broadly speaking, nutrient levels have increased often leading to problematic algal blooms, river pool anoxia and subsequent deleterious impacts on aquatic fauna. Historically there have also been elevated levels of pesticides in the river systems as a result of run-off from agricultural land.

Nutrient levels

Nutrient concentration in the lower Canning River tends to peak in winter due to mobilisation of large amounts of organic and dissolved inorganic nitrogen and phosphorus by winter flows. The first large rainfall event often transports the highest concentrations of nutrients which are deposited in river pools. The breakdown of this material increases the biological oxygen demand, in turn, reducing the oxygen content of the water column.

As flows decrease in spring, nutrient uptake by macrophytes and phytoplankton depletes available nutrients (WRC, 2002). Fortnightly monitoring of nutrient levels at McKenzie Grove on the Canning River is conducted as part of the catchment sampling program for the Swan-Canning Estuary (Figure 7). The 2005 measurements of total nitrogen and phosphorus demonstrate the typical seasonal variation of nutrients entering the lower Canning. Winter peak concentrations were in excess of ANZECC 2000 trigger values for lowland rivers (Figure 8 and

Figure 9). Soluble phosphorus, nitrate and ammonia winter peak levels were also in excess of ANZECC 2000 trigger values (Appendix D). Nitrate levels exceeded the trigger values throughout winter (up to 10 times the ANZECC trigger value) and spring.

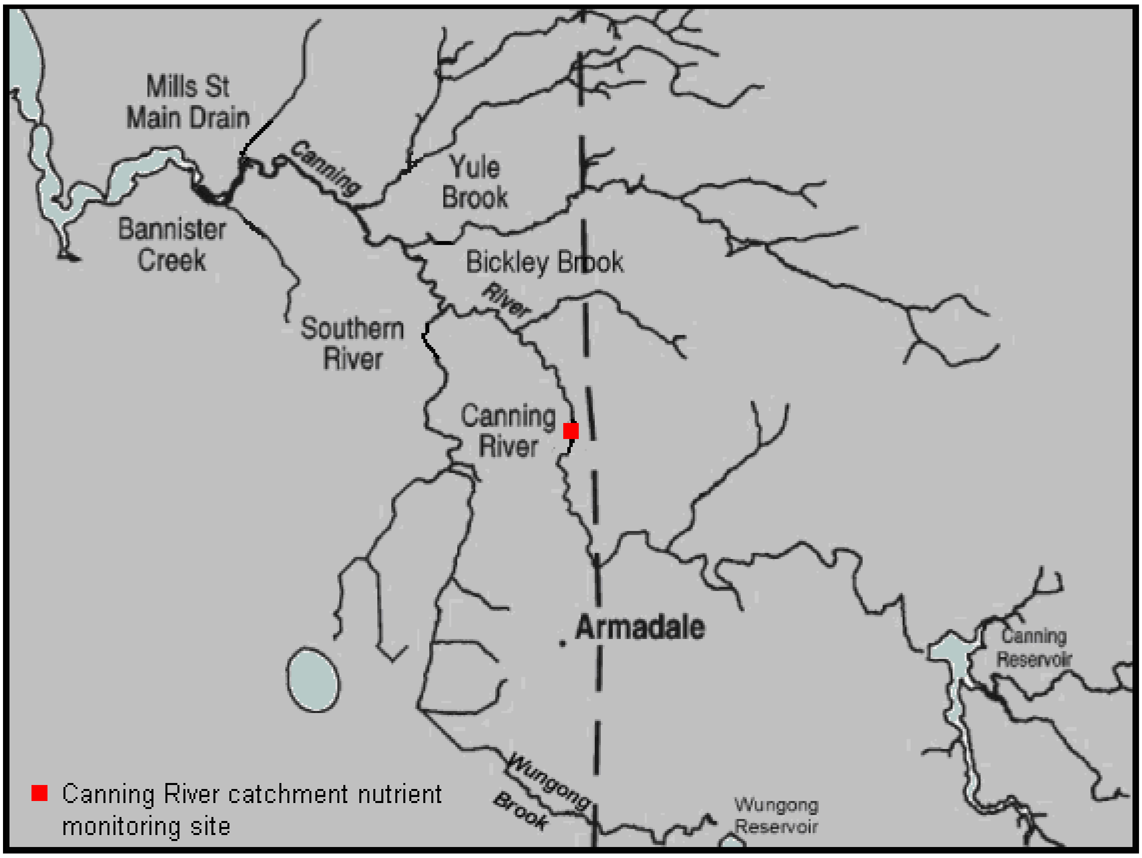

Figure 7: Location of Canning River catchment nutrient monitoring sites

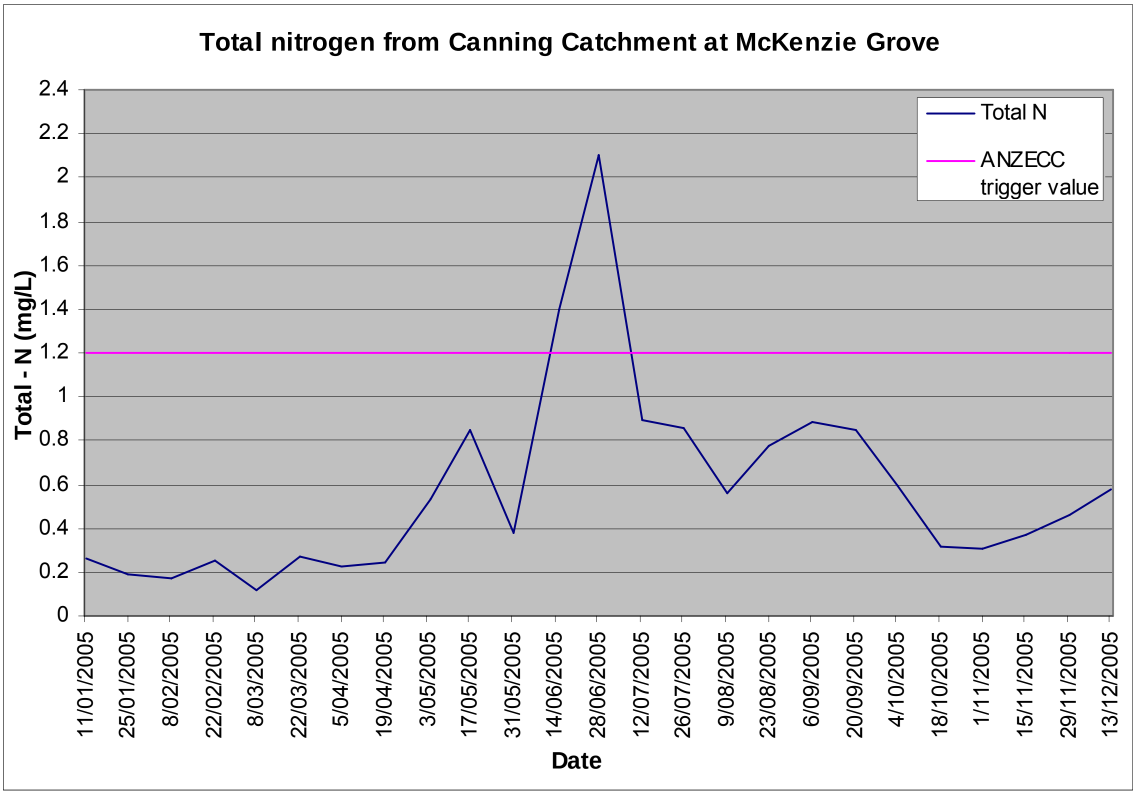

Figure 8: Total nitrogen measured fortnightly at McKenzie Grove in 2005

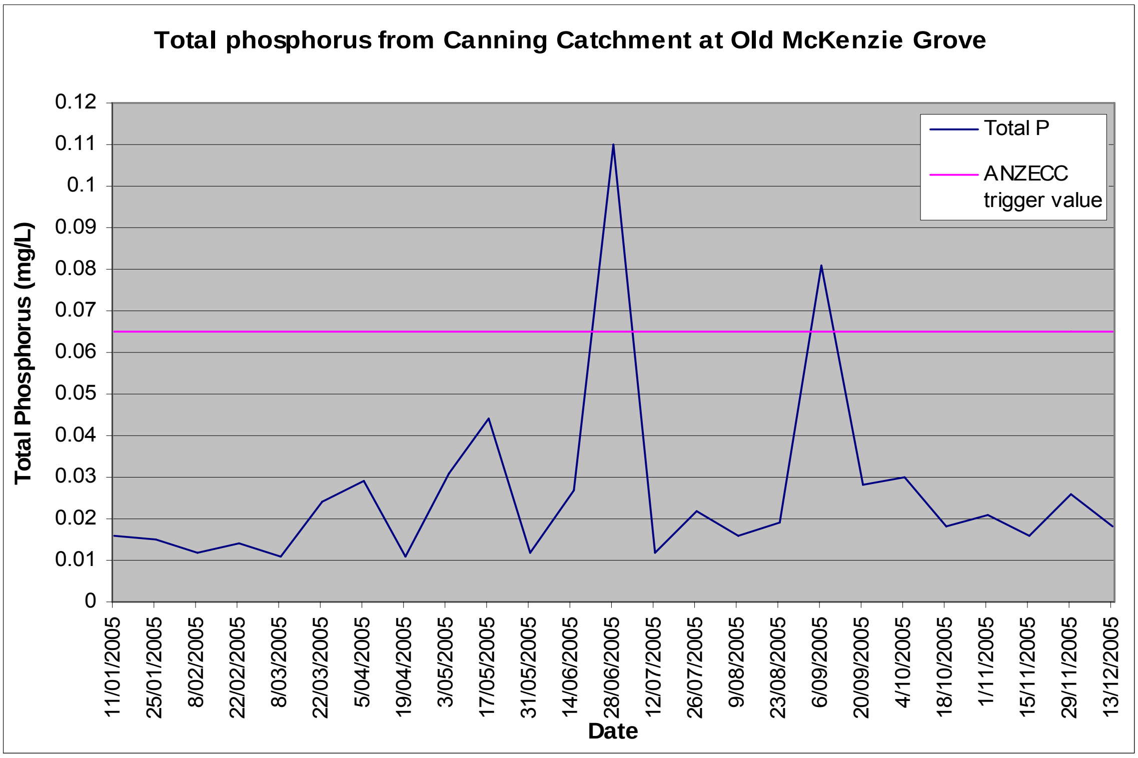

Figure 9: Total phosphorus measured fortnightly at Old McKenzie Grove in 2005

Pesticides

Runoff from surrounding agricultural and urban landuse can result in pollution of the river system by chemicals such as pesticides. The Aquatic Research Laboratory (1988) measured the bioaccumulation of organochlorine pesticides in the freshwater mussel, *Westralunio carteri*, in the Canning River. Two test sites were selected, both with mixed fruit orchards in their headwaters and runoff most likely containing pesticides. The results of the study indicated that although stream sediment samples measured minimal levels of all residues, bioaccumulation of pesticides occurred in mussels in both Stinton Creek and Kangaroo Gully. Results for Kangaroo Gully exceeded the maximum levels set at that time for freshwater fish tissue as recommended by the Australian National Health and Medical Research Council. Levels were high enough to endanger local fauna and human consumers (ARL, 1988). The control site at Thompson Road Bridge, 10-15km downstream of the test sites demonstrated no significant bioaccumulation of pesticides.

The Department of Water and the Department of Agriculture and Food are not aware of any monitoring of pesticides undertaken more recently than 1988. Organochlorine pesticides are no longer commonly used and have been replaced with pesticides such as organophosphate that don't bioaccumulate. It is likely that the pesticides currently entering the Canning River from surrounding rural land use have less impact on the ecology than previously used organochlorine pesticides. Monitoring of pesticides at the confluence of tributaries and the Canning would be required to confirm this.

Table 5: Water quality parameters measured in the macro-invertebrate monitoring program – Summer 1999

Parameter	**LC1** Upland site	**LC3** Upland site	**LC4** Upland site	**LC4C** Upland site	**LC6** Lowland site	**LC6A** Lowland site	**LC7** Lowland site	**LC7A** Lowland site	**ANZECC 2000** Upland river	**ANZECC 2000** Lowland river
Dissolved O_2 (top) %	60	81	77	54	53	37	67	64	90% Low limit	80% Low limit
Dissolved O_2 (bottom) %	60	91	75	45	42	37	65	37		
Temperature (ºC)	24.2	24.2	23.6	22.3	25	21.9	26.3	25.3		
Turbidity (NTU)	2.6	0.6	52	24	2.5	6.5	3	3	10-20	10-20
pH	6.92	6.75	6.59	6.37	6.62	6.7	6.89	7.03	6.5 - 8.0	6.5 – 8.0
Conductivity (μs/cm)	349	355	345	328	647	533	756	871	120 - 300	120 – 300
Colour (TCU)	47	8	27	16	25	2.5	61	77		

Total N (mg/L)	0.44	0.29	0.67	0.56	0.68	0.57	0.82	0.64	0.45	1.20
NH_3-N (mg/L)	0.03	<0.02	0.02	0.02	0.08	0.21	0.07	0.02	0.06	0.08
NO_3-N (mg/L)	0.02	<0.02	0.06	0.01	0.06	0.03	0.13	<0.02	0.2	0.15
Total P (mg/L)	0.01	0.01	0.05	0.03	0.02	0.02	0.07	0.11	0.02	0.065
P-SR (mg/L)	<0.01	<0.01	0.03	0.01	<0.01	<0.01	<0.01	0.08	0.01	0.04
Chlorophyll a (µg/L)	0.5	1	1	2	0.5	0.5	0.5	9	na	3-5

• Water quality parameters measured by Andrew Storey in February 1999 as part of macro-invertebrate monitoring project[2]

• ANZECC 2000 Guidelines are for South West Australia from Table 3.3.6, Volume 1, Chapter 3 National Water Quality Management Strategy[3]

• Highlighted values represent measurements above the ANZECC 2000 limit.

[2] Storey, A.W. (1999) Baseline monitoring of aquatic macro-invertebrates in the Canning River – Summer 1999. Report to the Water and Rivers Commission.

[2] National Water Quality Management Strategy (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1: The Guidelines

Dissolved Oxygen

Dissolved oxygen levels are an important feature of water quality and can strongly affect ecosystem health. Anoxia can cause the localised extinction of fauna and also result in the mobilisation of nutrients and some heavy metals from sediments further exacerbating water quality problems (WRM, 2005). Dissolved oxygen ≤ 2ppm is considered harmful to aquatic fauna (Section 3.3). In addition low, overnight dissolved oxygen levels (<40% saturation) may increase the potential for water quality problems through release of nutrients (*e.g.* phosphorus) and heavy metals from sediments (WRM, 2005).

Since 1984 the Aquatic Research Laboratory and more recently Wetland Research and Management have conducted physio-chemical parameter measurements during macro-invertebrate and fish monitoring on the Canning. The monitoring included sites on the Darling Scarp (Upper Canning) and on the Swan Coastal Plain (Lower Canning). Comparisons between measurements taken from sites during summer 1999 and the ANZECC 2000 Guidelines for rivers in the South-west Australia, (Table 5) shows some instances where dissolved oxygen appears to be the critical factor, exceeding the ANZECC trigger values on multiple occasions and at multiple locations.

The anoxic conditions that can occur during summer can further amplify this problem by releasing phosphorus and ammonium from the sediment (WRC, 2002). In the deeper pools, thermal stratification traps the released nutrients in the bottom waters. In shallow pools, the nutrients can extend throughout the water column and be taken up by plants and algae. The higher productivity further impacts water quality by increasing respiration activity at night, depleting the dissolved oxygen in the water column (Bunn *et al*., 2002).

Turbidity

Turbidity is the cloudy or muddy appearance of water caused by the suspension of particulate matter. Prior to regulation, the Canning River would naturally have possessed lower turbidity and higher water velocity. Bank erosion, erosion from livestock and urban and industrial developments has resulted in the current high turbidity in the river (Storey, 2002).

A study conducted by Wetland Research and Management (2000) provided information on the extent of bank and bed erosion/infilling of the Canning and Southern-Wungong rivers. The study determined that pool in-filling was occurring, resulting in reduced pool volumes and reduced habitat and functionality. With high respiration rates, reduced pool volumes can result in anoxia (oxygen depletion) and associated fish kills.

Temperature

Research has shown that in-stream water temperatures control ecological processes (i.e. ecosystem metabolism) and directly regulate biodiversity when upper lethal limits of resident aquatic fauna are exceeded. Water temperature can also indirectly control biodiversity and ecosystem health through changes in dissolved oxygen concentrations (Davies *et al.,* 2004). Greater light penetration due to clearing of riparian vegetation and reduced pool depth has lead to instances of high temperatures, particularly in summer.

Impact of impoundment and catchment management

Reduction in flows and the increased proportion of nutrient and sediment rich runoff to the lower Canning River has contributed to the eutrophic conditions that exist in the lowest reaches. Low water velocities and reduced flushing in the upper reaches of the river decreases mixing and aeration and results in low dissolved oxygen levels in summer (ARL, 1988d). The lack of ‘flushing flows’ has resulted in considerable accumulation of organic material in the large bed-rock controlled pools on the Darling Scarp (WRM, 2000). Significant accumulation of organic material and fine sediments, of approximately 300-600mm depth, are common in permanent pools within the mid and lower reaches of the Canning River system (Bernard Road, Orlando Street, Manning Avenue, and Pioneer Park).

Flow related issues and considerations

Water velocity is a vital component in ensuring adequate mixing and aeration. To reduce the likelihood of anoxia of the water column and assist in the transfer of nutrients, flows must also ensure that the connectivity of pools is maintained in summer. Flushing flows in winter are required to reduce the nutrient load in pools resulting from the accumulation of organic and inorganic material.

The formation of algal blooms in lowland rivers and pools is linked to periods of low flow. Blooms do not develop during periods of high flow as blue-green algae are continually washed downstream and are not able to accumulate. Sheffer (1998), reports that blue-green algae dominance has not been observed in lakes where the hydraulic retention time is less than five days.

It has been estimated that a retention time of less than two weeks for surface waters would be sufficient to prevent anoxia in the Kent Street Weir Pool (Robb. M. pers.comm, 2006). This requirement has been used for the remaining larger pools in the Canning (ie. Pioneer Park, Manning Avenue, Orlando Street and Bernard Road). However, the characteristics of these pools differ in size and average depth from the Kent Street Weir pool, and as such, this recommendation can only be used as an approximation. It is likely that the smaller volume pools of the Canning River will require shorter periods of retention to counter the effects of anoxia.

Flow objectives

- Flows to maintain connectivity of pools in summer.
- Flows to prevent significant stratification or anoxia in pools during summer (hydraulic retention time of less than two weeks).
- Flushing flows in winter to reduce nutrient concentrations and associated water quality problems in summer.

3.6 Riparian vegetation

Maintenance of an adequate zone of riparian vegetation is vital to the health of rivers and streams. Riparian vegetation:

- reduces the risk of erosion;
- plays a vital role in shading streams and reducing water temperature;
- provides an important source of carbon, in the form of leaf litter, to rivers which contributes to in-stream food webs;
- contributes to in-stream habitat in the form of large woody debris; and
- provides important stream side habitat for terrestrial fauna (Davies *et al.,* 2004; Nilsson *et al.,* 1993; Pettit and Froend, 1999).

The health and recruitment of riparian vegetation communities is linked to flow regimes. Water in the riparian zone has vertical (water level fluctuations) and horizontal (flow) components that can have direct (mechanical and physiological) and indirect (redistribution of soil and litter, replenishment of soil and groundwater) effects on riparian processes (Nilsson *et al.,* 1993). The timing, frequency, duration and energy of water flow are the main aspects of fluvial regime that influence riparian vegetation.

Flood flows or flows that reach the riparian zone vegetation may be important in:

- distributing propagules;
- influencing community composition and succession through disturbance; and
- maintaining sufficient levels of soil moisture to facilitate plant growth and seedling germination.

The Canning River catchment has been heavily cleared for urban development, agriculture and construction of drainage channels for flood control (Swan River Trust, 1993; Storey, 2002). This has resulted in the modification or loss of much of the natural riparian vegetation along reaches of the Canning and Southern-Wungong rivers. Large sections of the river and its tributaries retain little native understorey, are dominated by weeds and are heavily eroded (ARL, 1988; ARL, 1988b; ARL, 1989; Swan River Trust, 1993; Storey, 1998; and Storey 2000). Where riparian vegetation is present, the width of riparian zone has often been greatly reduced, only extending a few metres either side of the channel (Shepherd and Siemon, 1999).

Native understorey species were generally restricted to clumps of native sedges and rushes such as pale rush (*Juncus pallidus*) along foreshore channels and low-lying damp areas (Shepherd and Siemon, 1999). The combination of removal of native species, increased nutrient levels and a high level of disturbance of the riparian environment provides ideal conditions for ruderal (typically exotic annual) species (Storey, 2002).

The Swan River Trust (1993), using aerial photography, suggested that the cover of native over-storey species such as *Melaleuca rhaphiophylla* and *Eucalyptus rudis* had increased during the period 1941 to 1991. This was primarily attributed to altered land use and a shift from agricultural landuse to urbanisation. This has allowed increased regeneration and re-colonisation by native species, an observation supported by Pettit and Froend (1999) who emphasized the importance of the impact of grazing on riparian zones in their comparative study on the Blackwood and Ord Rivers.

The Swan River Trust (1993) identified and mapped dominant vegetation communities along the Canning, Southern and Wungong rivers. Brief summaries of the communities described are provided in Table 6.

Table 6: Riparian vegetation communities of the Canning River (taken from Swan River Trust 1993).

Riverine fringing vegetation
Melaleuca rhaphiophylla low open to closed forest
Eucalyptus rudis – M. rhaphiophylla open to closed forest
Typha orientalis tall closed sedgeland
River valley embankment vegetation
Eucalytpus rudis – Corymbia calophylla open-closed forest
Corymbia calophylla open closed forest
Eucalyptus marginata – Corymbia calophylla open forest-woodland
Floodplain and wetland vegetation
Acacia saligna low closed forest
Juncus closed sedgeland
Schoenoplectus validus tall closed sedgeland
Baumea articulata tall closed sedgeland
Winter wet depression vegetation
Winter wet depression complex

Sandy rise vegetation
Banksia-Allocasuarina-Eucalyptus todtiana low open forest.

Storey (2002) identified a number of remnant freshwater wetlands and tidal lagoons that are still associated with the lower reaches of the Lower Canning. Each of the wetlands was connected to the main river channel and/or lie within the floodplain and some retained native vegetation. The wetland sites were considered to be of significant ecological value for wildlife conservation and provide habitat for waterfowl, fish and macro-invertebrate species (Storey, 2002).

The Canning River also supports populations of submerged aquatic macrophytes. Whilst studies in other river systems have shown that submerged macrophytes typically do not directly support food webs, they do provide habitat for macro-invertebrates and fish and a substrate for epiphytic algae. Braimbridge (1996) demonstrated that macrophyte populations within the lower reaches of the current study area varied spatially and temporally, with biomass peaking over summer in relatively shallow (<2m) and open (i.e. open riparian canopy) parts of the channel. Areas of submerged macrophyte reduced significantly over winter and it was suggested that this was related to flow velocity, turbidity and light availability.

Impact of impoundment and catchment management

River regulation has the potential to change vegetation species distribution and composition by altering the hydrologic regime of the riparian zone. There is also potential for reduced opportunities for regeneration/colonisation by native species (Pettit and Froend, 1999). Dams can disrupt dispersal mechanisms and cause fragmentation of formerly continuous vegetation communities. Reduced flooding and water levels can reduce the size of the riparian zone, allowing down slope migration of species not tolerant of flooding.

The impoundment of the Canning and Southern-Wungong rivers has reduced flows and modified the floodplain and riparian vegetation. Remnant riparian vegetation does not receive the winter and spring flooding typical of the river system prior to impoundment. There is less inundation of riparian vegetation and off channel wetland areas, and at some sites there is encroachment of vegetation, particularly weed species, choking the main channel.

There is also potential for regulation to increase the distribution and abundance of submerged aquatic macrophytes. By reducing the frequency and size of large flood flows which would in a pre-regulation system scour macrophyte populations and the sediment beds upon which they grow, regulation increases the habitat and growing season available to submerged macrophytes (Trayler *et al.,* 2006). However, this is not necessarily a negative impact. Given the reduced frequency of flooding of and connectivity with off-channel wetland areas, macrophyte beds may provide a similar ecological niche, effectively replacing or complimenting the ecological niche previously provided by off channel areas.

Recent and ongoing changes in landuse in much of the catchment from agricultural to urban, has decreased grazing pressure on riparian vegetation in much of the catchment. This presents an opportunity for increased restoration of riparian vegetation communities if coupled with adequate management of weeds, fire and human traffic. Any restoration activities need to be coupled with consideration of the flow regime so revegetation activities suit the existing flow regime. Similarly any alterations to the flow regime need to be designed to compliment restoration activities.

Flow related issues and considerations

Many species of riparian vegetation, such as *Baumea* spp., are dependent on seasonal inundation to stimulate the dispersal and germination of seed. Regulated rivers, altered flow regimes and flooding patterns can restrict regeneration opportunities and cause changes to species composition and structure in the riparian zone (Pettit, 2000). On the Murray River in eastern Australia, changes in the degree, frequency and season of flooding has resulted in a lack of recruitment of native species (Dexter, 1978 cited in Pettit, 2000). Maintaining a natural winter and spring flood regime assists successful recruitment of seeds, establishment of seedlings and development of native riparian plant communities.

The distribution of species within the riparian zone, and beyond, often reflects differing species requirements for water and/or tolerances to inundation (Pen, 1981; Webb *et al.,* 2006). For example, *Melaleuca rhaphiophylla* exhibits a greater flooding tolerance than *Eucalyptus rudis* and as such is often found lower in the riparian zone (Pettit and Froend, 1999).

Alteration of flows and the hydrologic regimes for different parts of the riparian zone can result in changes in patterns of species distribution and possibly even the loss of species (Nilsson *et al.,* 1997).

Reduced flows can severely degrade the health and extent of riparian vegetation. Maintenance of a sufficient natural flow regime is important to ensure germination, recruitment and colonisation of native vegetation. Flows also need to be sufficient to recharge and maintain soil water that sustains and promotes vegetation growth rates and seedling survival (Pettit and Froend, 1999).

Failure to provide flows to promote recruitment and survival of intact riparian vegetation communities may result in thinning or a reduction in health of the riparian zone. Resultant degradation of the riparian zone can increase erosion and further degrade the stream bank; increase sedimentation downstream; and reduce shade and in-stream habitat.

Flow objectives

- Water to maintain and/or allow restoration of wetlands/riparian vegetation in winter-wet pastured floodplain regions and along the periphery of drainage channels.
- Inundation of wetlands/ riparian vegetation in winter-wet vegetation to allow restoration and maintenance of these areas.
- Seasonal inundation of emergent vegetation (survival, germination and recruitment).
- Seasonal inundation of mid bank vegetation (above emergent zone) (survival, germination and recruitment).
- Flows to maintain populations of submerged macrophytes and maintenance of sufficient population during low flow periods for re-colonisation.

3.7 Ecosystem processes

Current state

Stream and river ecosystems are a vital component of the landscape and ecological boundaries often extend to the entire catchment. Catchments provide water (surface and groundwater), nutrients and food for aquatic fauna.

The Canning River is influenced by a seasonal 'predictable' flow regime which consists of intermittent streams in the forested Darling Scarp catchment flowing into a permanent lowland river system. As with many other river systems in the south-west, impoundment of the headwaters and the recent drying period (1974 to present) has restricted the transportation of water, nutrients and food (leaf litter) to the lower reaches of the river system. It is important that connectivity between forest and lower reaches is maintained. Inputs from tributaries below reservoirs provide a significant component in impounded systems (Storey *et al.,* 2002). The Canning River system has few tributaries originating from the forested catchment that are not impounded. Stinton Creek is one such example and hydrological modelling has demonstrated that post regulation the relative importance of the contribution of Stinton Creek to the mean annual discharge in the lower Canning River has increased (Storey *et al.,* 1991) (see Section 3.2). This tributary is an important component in providing seasonal flow and thereby likely provides an upstream-downstream linkage in energy flow.

The Flood Pulse Concept (Junk *et al*., 1989) emphasises the link between the river and its floodplain. These links occur during large flood events when material from the floodplain is transported into the river channel when floods recede. As described in Section 3.1, the lower reaches of the Canning River are characterised by a highly regulated hydrology and incised river channel. This has reduced the river-floodplain connection. Although discharge measurements at Seaforth Gauging Station indicate that 'flood pulse' events capable of entering the floodplain do occur, the highly disturbed nature of the riparian vegetation would likely result in limited transfer of carbon (e.g. leaf litter) into the river system and would more likely result in increased erosion of the river bank leading to a greater sediment load depositing in shallow pools. In the bedrock controlled upper reaches of the system, sections of riparian vegetation remain intact. Recently installed gauging stations have not measured flows capable of reaching the floodplain but continued monitoring may find sufficient discharges do occur. Overall, it is unlikely that the Flood Pulse Concept describes energy flow in the Canning River (Storey *et al.,* 2002).

The River Productivity Model may be more appropriate for the Canning River considering its highly modified state. The model emphasises the importance of local carbon inputs in providing energy to the system (Storey *et al.,* 2002). Seasonal inundation of benches is required to provide inputs of autochthonous (algal production) and allochthonous energy (leaf litter/detritus) which support components of in-stream food webs. Algal production on seasonally inundated in-stream benches, backwaters and in shallow pools is important in supporting aquatic food webs. (Davies, 1993; Welker & Davies, 1998; Davies *et al.,* 1998). Carbon inputs in the form of in-stream primary production dominates in the lower reaches (Davies, 1993; Welker & Davies, 1998; Davies *et al.,* 1998) and is supported by the peak of nutrients measured in winter (see Section 3.5). For the upper reaches direct inputs from adjacent riparian vegetation, via allochthonous transfer, plays an important role in the energy transfer within the system and for supporting associated aquatic fauna (Storey *et al*., 2002).

Flow related issues and considerations

Impoundment of the Canning River and most major tributaries has drastically reduced the volume of water within the river system, particularly in summer. Monitoring has shown that Stinton Creek, the first major tributary downstream of the dam, provides seasonal flow and in effect 'resets' the physical parameters and ecology (see Section 3.2). This has likely resulted in a seasonal regime where energy would be transported from the upper reaches and associated tributaries to the lower reaches during winter as per the River Continuum Concept.

Monitoring has also suggested that without the six release points along the river system, connectivity would not be maintained in the summer months and extended periods of no flow conditions would likely result. Discharge from the release points supports connectivity within the system but does not contribute to the energy-flow. The system would be further supported by local carbon inputs such as in-stream algal production, as per the River Productivity Model, in summer. Presently prescribed releases provide an important role of ensuring sufficient water exists in the system to limit the likelihood of anoxia of the water column and to support algal growth such as phytoplankton, benthic algae, epiphytic growth on macrophytes which in turn supports foodwebs. Sufficient summer flows to transport allochothonous energy sources from in-stream benches, backwaters, and tributaries are required to support aquatic fauna.

Flow objectives

- Seasonal inundation of riparian zones for allochthonous litter transfer.
- Maintenance of flow connectivity between upstream and downstream reaches for energy transfer.
- Seasonal inundation of instream benches for algal production.

4 Summary of issues and objectives

The flow objectives and considerations for each environmental attribute discussed in this document are summarised in the table below.

Table 7. Summary of issues and objectives

Ecological Attribute	Ecological objective	Reach	Flow considerations: Flow component	Season/ Timing	Hydraulic Factors/ Constraints
Geomorphology					
Maintain an active channel	Sufficient flows to scour pools and remove accumulated sediments and organic material	All reaches	Flow velocity of 20-30 cm/sec 1:10 / 1:20 year flood mimic	Winter	Flow velocity or bank full/over bank flows
	Sufficient flows to maintain the shape of the active channel	Middle and lower reaches	Active channel flows	Winter	Flow velocity or discharge to meet active channel height
Macro-invertebrates					
Maintain the species richness and composition of macro-invertebrate communities	Maintain a height of 5-10cm over gravel runs and riffles as biodiversity 'hotspots' for macro-invertebrates	All reaches	Low flows	All months	5cm over 25% of riffle width
	Flows to maintain submerged macrophyte beds as habitat for macro-invertebrates	Middle and lower reaches	Low flows	All months	50cm in pools (min cont level) 20cm in drought
	Sufficient stage height to ensure marginal reeds/rushes are trailing and providing habitat for macro-invertebrates	All reaches	Low flows	All months	Low-med flow levels
	Maintain overbank flows to inundate the floodplain and provide shallow floodplain and backwater areas for habitat and avoidance of high flows	Middle and Lower reaches	High flows	Winter	Sufficient flow to exceed banks (ARI < 1:5?)
	Flows to maintain connectivity of pools in summer	Middle and lower reaches	Low flows	Summer	Min flow over barriers (incl. man-made impoundments)
	Flows to prevent significant stratification or anoxia in pools during summer	Middle and lower reaches	Low flows	Summer	Minimum velocity needs to be determined
	Flows to maintain macro-invertebrate community structure typical of reach location	All reaches	Seasonal and predictable flows	All year	

Ecological Attribute	Ecological objective	Reach	Flow considerations Flow component	 Season/ Timing	 Hydraulic Factors/ Constraints
Fish					
Maintain species richness and composition of fish communities. Manage introduced species.	Sufficient water depth to provide fish passage for reproductive migration	All reaches	High flows	Late autumn to early summer	Sufficient flow to drown out barriers. ≥ 0.175m for nightfish, western pygmy perch and western minnow. ≥ 0.2m for Cobbler
	Oxygen levels are maintained above 2mg/l to avoid fish kills.	Middle and lower reaches	Low flows	Summer/ Autumn	Minimum velocity needs to be determined
	Inundation of ≥ 0.1m for emergent and trailing sedges and rushes to provide fish habitat and spawning and recruitment.	All reaches	High flows	Late autumn through winter and into early spring	
	Flows to maintain connectivity of pools in summer	All reaches	Low flows	Summer	Min flow over barriers
	Flows to maintain submerged macrophyte bed habitat for fish	Middle and lower reaches	Low flows	All months	50 cm in pools ideal, 20cm in drought conditions
	Sufficient water to maintain pool depth for Cobbler nests and as refuge habitat for other fish species	All reaches	Low flows	Summer/ Autumn	Pools >80cm - ideal; >50cm – drought conditions
	Provide shallow backwater areas for nursery areas for juvenile fish to avoidance predators and habitat for smaller bodied fish and areas to avoid high flows in the main channel	Middle and Lower reaches	High flows	Late autumn through winter and into early spring	Min depth in secondary channels. 20cm
	Provide sufficient water to prevent sediment aggradation to maintain habitat and functionality of pools for fish.	Middle and lower reaches	High flows	Winter	Flow velocity or bank full/over bank flows
	Provide overbank flows to inundate and connect floodplain wetlands and shallow-flooded off-river areas for foraging and spawning habitat for native fish	Middle and Lower reaches	High flows	Late autumn through winter and into early spring	Sufficient flow to exceed banks

Ecological Attribute	Ecological objective	Reach	Flow considerations Flow component	 Season/ Timing	 Hydraulic Factors/ Constraints
	Undercutting to provide habitat for fish	All reaches	Low flows	All months	Inundate top of undercut spot heights
	Flows to inundate instream benches to provide foraging areas and spawning habitat for fish	All reaches	High flows	Winter/Spring	Inundation to depth of 10cm
Waterbirds					
Maintain habitat to support waterbird communities.	Maintain permanent pools as a summer and drought refuge for waterbirds	All reaches	Low flows	All year	50cm ideal, 20cm in drought conditions
	Maintain flows to protect riparian vegetation, particularly seasonally inundated vegetation that may provide breeding habitat.	All reaches	High flows	Winter	As per riparian vegetation objectives
	Maintain adequate flow to protect key habitat sites.	All reaches	Low flows	All year	Dependant on identification of key habitat
Water quality					
Prevent de-oxygenation of the water column	Flows to maintain connectivity of pools in summer	Middle and lower reaches	Low flows	Summer	Min flow over barriers
	Flows to prevent significant stratification or anoxia in pools during summer	Middle and lower reaches	Low flows	Summer	Minimum velocity needs to be determined
	Flushing flows in winter to reduce nutrient concentrations and associated water quality problems in summer	All reaches	High flows	Winter	1m above baseflow?
Riparian vegetation					
Maintain the diversity of the riparian zone and bank stability	Water to maintain and/or allow restoration of wetlands/riparian vegetation in winter-wet pastured floodplain regions and along the periphery of drainage channels	Lower reach	High flows	Winter	Over bank flows

Ecological Attribute	Ecological objective	Reach	Flow considerations		
			Flow component	**Season/ Timing**	**Hydraulic Factors/ Constraints**
	Inundation of wetlands/riparian vegetation in winter-wet vegetation to allow restoration and maintenance of areas.	All reaches	Highflows	Winter	Over bank flows
	Seasonal inundation of mid bank vegetation (above emergent zone) (survival, germination and recruitment)	All reaches	High flows	Winter	1m above baseflow
	Flows to maintain populations of submerged macrophytes and maintenance of sufficient population during low flow periods for recolonisation.	Middle and lower reaches	Low flows	Summer	50cm in pools, 20cm in drought conditions
Ecosystem Processes					
Maintain transfer of energy to downstream systems.	Seasonal inundation of riparian zones for allochthonous litter transfer	All reaches	High flows	Winter	1m above baseflow?
	Maintenance of flow connectivity between upstream and downstream reaches for energy transfer	All reaches	Low Flows	All year	Min flow over barriers
	Seasonal inundation of lower benches for algal production	All reaches	High flows	Winter	50cm above baseflow (reliant of winter spates)

5 Development of ecological water requirements

The flow related issues and objectives presented in this document will be used to guide the determination of ecological water requirements for the Canning River and contribute ultimately to the development of a water resource management plan. The proposed process for developing ecological water requirements is outlined below.

Flow Events Method

Ecological water requirements will be developed using the Flow Events Method (Stewardson & Cuningham, 2002). The Flow Events Method was designed to provide a rigorous, holistic, standardised, transparent and analytical procedure for determining water requirements (Stewardson & Cunningham, 2002).

Central to the Flow Events Method is the principle that various flow components (e.g. summer and winter base flows, bankfull flows and flood flows Figure 11) have different ecological functions and that these need to be considered independently (Cottingham *et al.,* 2003; Stewardson & Cottingham, 2002; Stewardson & Gippel, 2003). Even periods of no flow may be important, e.g. in ephemeral and seasonal systems.

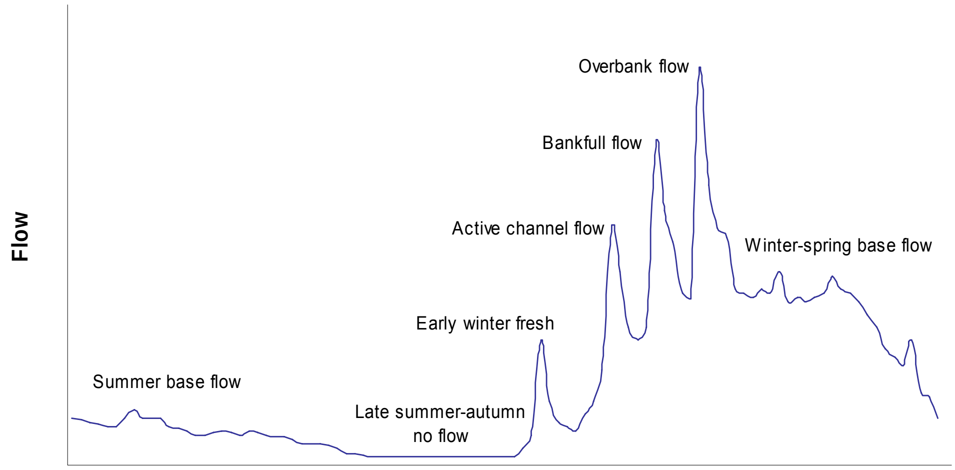

Figure 10: *Time series showing typical components (events) of a natural flow regime relevant to river systems in south-west Australia* (Cottingham *et al.*, 2003)

One of the main principals of the approach is that an altered river ecosystem (e.g. downstream from impoundments or abstraction) incorporates integral or 'key' ecological features of the original functional system; i.e. some of the natural flow variability should remain.

Application of the Flow Events Method

The development of flow recommendations under the Flow Events Method typically has two stages (Cottingham *et al.*, 2003) (Figure 11). The first stage includes documentation of the representative sites and reaches, field assessments and the development of an issues paper highlighting environmental assets, threats and flow-related ecological objectives that will provide the basis for the environmental flow recommendations. The finalisation and publication of this document represents the completion of the first stage of the determination of an ecological water requirement for the Canning River.

The second stage of the method involves hydraulic surveys and modelling (already commenced) as well as hydrological analyses to develop flow recommendations (i.e. ecological water requirements) that address the flow related objectives outlined in the issues paper.

The Flow Events Method process for the Canning River system has been refined to suit the unique circumstances of the project. A hydraulic model has been created for six monitoring sites that are representative of the Canning River system. A Technical Working Group, with specialist guidance from, and scientific consultation with, Dr Andrew Storey (Wetlands Research and Management), was established and undertook site assessments to determine ecological objectives and flow-ecology linkages.

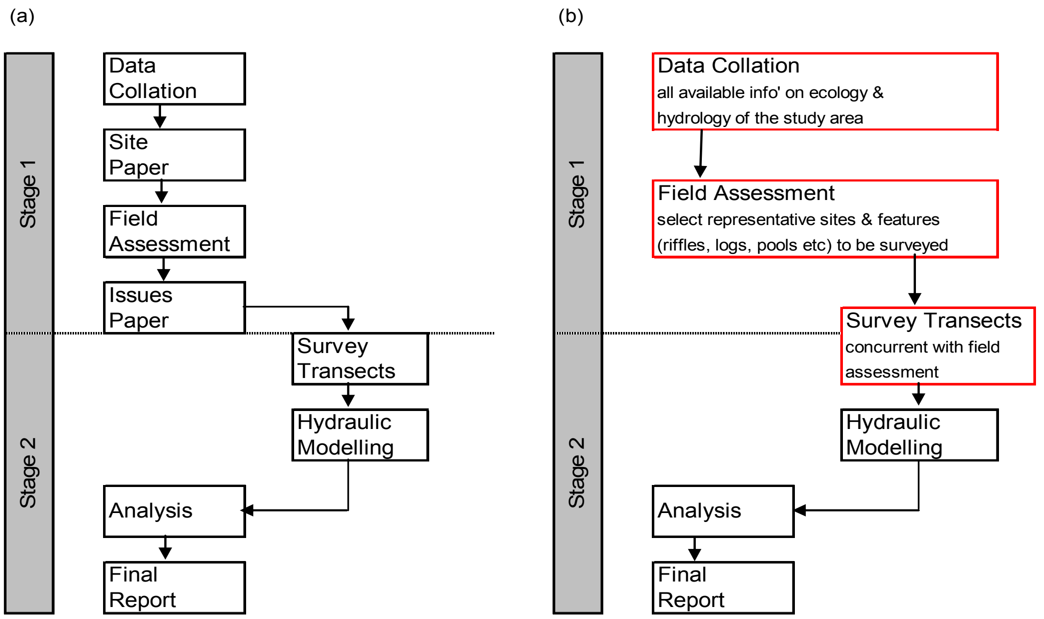

Figure 11a: Basic steps in the Flow Events Method and (b) steps used in the current study [3]

[3]Boxes in red emphasise modifications made for the current study.

5.1 Complementary management

This report does not attempt to directly address the wider range of integrated catchment management issues facing the Canning River system. However, a number of complementary management initiatives will need to be undertaken in order to improve environmental outcomes for the system. These include:

- Reduction in nutrient and pesticide concentrations in drainage water;
- Consideration of options for endemic fish species and fish passage past current impoundments (Kent Street Weir, Kelmscott, Seaforth, Agostino Rd, Brookton Hwy, Soldiers Rd, and YHA locations);
- Implementation of riparian weed control strategies;
- Implementation of river restoration to improve habitat diversity and hydraulic factors connectivity between each management reach;
- Control of sediment inputs from surrounding developments, particularly for site erosion control in the steeper upstream reaches and erosion prone soils of the tributaries and coastal plains adjacent to the Canning River; and
- Implementation of a sedimentation management program for low-energy pools within the Canning River system.

Glossary

Abstraction	The permanent or temporary withdrawal of water from any source of supply, so that it is no longer part of the resources of the locality.
Aboriginal heritage	Includes both the physical and cultural aspects and relates to the significance of places and objects to Aboriginal people in terms of traditions, observations, customs and beliefs.
Allocation limit	The quantity of water available for consumptive use, after Environmental Water Provisions and domestic requirements have been set. Domestic Allocation: refers to the volume of water required for household purposes and the irrigation of a small domestic garden.
Aquifer	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Usually described by whether they consist of sedimentary deposits (sand and gravel) or fractured rock. Aquifer types include unconfined, confined and artesian.
Biodiversity	The variety of organisms, including species themselves, genetic diversity and the assemblages they form (communities and ecosystems). Sometimes includes the variety of ecological processes within those communities and ecosystems. Biodiversity has two key aspects: its intrinsic value at the genetic, individual species, and species assemblages levels; and ·its functional value at the ecosystem level. Two different species assemblages may have different intrinsic values but may still have the same functional value in terms of the part they play in maintaining ecosystem processes.
Conservation	The management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations, while maintaining its potential to meet the needs and aspirations of future generations. Thus conservation is the positive, embracing, preservation, maintenance, sustainable utilisation, restoration and enhancement of the natural environment.
Dissolved oxygen	The concentration of oxygen dissolved in water or effluent, normally measured in milligrams per litre (mg/L).
Ecological values	The natural ecological processes occurring within water-dependent ecosystems and the biodiversity of those systems.
Ecological water requirements	The water regime needed to maintain ecological values of water-dependent ecosystems at a low level of risk.

Ecosystem	A community or assemblage of communities of organisms, interacting with one another, and the specific environment in which they live and with which they also interact, e.g. lake, to include all the biological, chemical and physical resources and the interrelationships and dependencies that occur between those resources.
Environment	Living things, their physical, biological and social surroundings, and interactions between all of these.
Environmental water provisions	The water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social and economic values. They may meet in part or in full the ecological water requirements.
Evaporation	Loss of water from the water surface or from the soil surface by vaporisation due to solar radiation.
Evapotranspiration	The combined loss of water by evaporation and transpiration. It includes water evaporated from the soil surface and water transpired by plants.
Gigalitre (GL)	A commonly used term to measure large volumes of water, equal to 1 billion litres, 1 million cubic metres or 1 million kilolitres (kL).
Groundwater	Water found under the land surface which occupies the pores and crevices of soil or rock.
Groundwater area	An area proclaimed under the *Rights in Water and Irrigation Act 1914* in which private groundwater abstraction is licensed.
Groundwater availability	The annual amount of groundwater available for abstraction, equal to the allocation limit minus any licensed entitlements.
Hectare (ha)	Hectare-10,000 square metres or 2.47 acres.
Kilolitre (kL)	1 Kilolitre= 1,000 litres, 1 cubic metre or 220 gallons.
Levee	An artificial embankment or wall built to exclude flood waters, or a natural formation adjacent to a waterway built by the deposition of silt from floodwaters.
Licence	An authority to carry out an activity, usually issued under the powers of a particular Act of a parliament. Carrying out the activity without a licence where one is required is illegal and an offence against the Act.
m AHD	Australian Height Datum – height in metres above Mean Sea Level + 0.026 m at Fremantle.
m^3/sec	Cubic metres per second.
Megalitre (ML)	Unit of (water) volume; one million litres, a thousand kilolitres or a thousand cubic metres.

Mt/yr	Million tonnes per year.
Policy	A definite course of action adopted as expedient or from other considerations.
ppt	Parts per thousands, same equivalent as grams/litres.
Precautionary principle	Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason to postpone measures to prevent environmental degradation. In the application of the precautionary principle, public and private decisions should be guided by: careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment; and an assessment of the risk-weighted consequences of various options. This provides an approach for considering the environmental impacts of a proposal on biodiversity values where there is a lack of knowledge and lack of scientific certainty. A useful methodology for applying the precautionary principle is that of Deville and Harding (1997).
Recharge area	An area through which water from a groundwater catchment percolates to replenish (recharge) an aquifer. An unconfined aquifer is recharged by rainfall throughout its distribution. Confined aquifers are recharged in specific areas where water leaks from overlying aquifers, or where the aquifer rises to meet the surface. Recharge of confined or artesian aquifers is often at some distance 'up flow' from points of extraction and discharge.
Salinity	The measure of total soluble (or dissolved) salt, i.e. mineral constituents in water. Water resources are classified on the basis of salinity in terms of Total Soluble Salts (TSS) or Total Dissolved Salts (TDS). TSS and TDS are measured by different processes, but for most purposes they can be read as the same thing. Measurements are usually in milligrams per litre (mg/L) or parts per thousand (ppt). Measurements in ppt can be converted to mg/L by multiplying by 1,000, e.g. seawater is approximately 35 ppt or 35,000 mg/L TSS. Salinity is also often expressed as electrical conductivity, measured by an electronic probe (conductivity meter). Water resources are classified as fresh, marginal, brackish or saline on the basis of salinity.
Social water requirements	Elements of the water regime that are identified to meet social (including cultural) values.
Surface water	Water flowing or held in streams, rivers and other wetlands on the surface of the landscape.
Sustainability	Measure at the extent to which the needs of current and future generations are met through integration of environmental protection, social advancement and economic prosperity.

Sustainable yield	The limit on potentially divertible water available from a source is determined after taking account of "in-stream" values and making provision for environmental water needs, so that water extraction does not cause lowering of the watertable, intrusion of more saline water or environmental damage. The level of extraction measured over a specified planning timeframe that should not be exceeded to protect the higher value social, environmental and economic uses associated with the aquifer.
Water conservation	The management of water use to achieve and maintain an appropriate level of water use efficiency.
Water-dependent ecosystems	Those parts of the environment, the species composition and natural ecological processes of which are determined by the permanent or temporary presence of water resources, including flowing or standing water and water within groundwater aquifers.
Water efficiency	The minimisation of water use through adoption of best management practices.
Water entitlement	The quantity of water that a person is entitled to take on an annual basis as specified on a licence held by that person, and issued under the licensing powers of the *Rights in Water and Irrigation Act 1914*.
Water services provider licence	A licence issued under the provisions of the *Water Services Licensing Act 1995,* by the Economic Regulation Authority.
Water licence	A licence issued under the licensing provisions of the *Rights in Water and Irrigation Act 1914.*
Water resources	Water in the landscape (above and below ground) with current or potential value to ecosystems and the community.
Water regime	A description of the variation of flow rate in surface water or water level over time; it may also include a description of water quality.
Watercourse	A river, stream or creek in which water flows in a natural channel, whether permanently or intermittently.
Watertable	The saturated level of the unconfined groundwater. Wetlands in low-lying areas are often seasonal or permanent surface expressions of the watertable.
Well	A hole dug or drilled into an aquifer to monitor or abstract groundwater.
Wetland	Wetlands are areas that are permanently, seasonally or intermittently waterlogged or inundated with water that may be fresh, saline, flowing or static, including areas of marine water the depth of which at low tide does not exceed 6 metres. In WA, the term 'wetland' is commonly used to describe that subgroup of non-marine wetlands that are in basin or flat

form (such as lakes, sumplands, damplands and palusplain), with the term ‘waterways’ more commonly used to describe those occurring in channel form (such as rivers and streams).

Most definitions have been taken from the Department of Water’s glossary located at http://portal.water.wa.gov.au/portal/page/portal/dow. The remainder were defined specifically for the purpose of this document.

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Appendices

Appendix A — Endemic freshwater species

Western minnow (*Galaxias occidentalis*)

Family: Galaxiidae

A small freshwater fish with scaleless, very elongated body, the western minnow, together with the western pygmy perch, is the most widespread of the freshwater fishes endemic to south-western Australia. It is common and abundant in rivers, streams, lakes and pools that are connected to streams. This fast-swimming species is often seen close to riparian vegetation but has been observed in fast-flowing water near rapids and waterfalls and in large schools in slow-moving streams and open water. Studies have found the western minnow to consume a diet of mainly terrestrial invertebrate fauna during the day and the freshwater shrimp *Palamonetes australis* at night. The fish typically lives for two years with individuals recorded reaching sexual maturity and spawning at the end of the first year of life. Spawning only occurs once during each breeding season. The western minnow begins an upstream migration into tributaries and temporary headwater streams with the onset of winter rain. The fish spawn amongst flooded vegetation between early June and late September with peak breeding occurring in August as the mean monthly water temperatures begin to rise or possibly initiated by a sharp rise in temperature (Pen & Potter, 1990a). Although temperature appears to be a crucial trigger, water flow characteristics may also be important. According to Pen and Potter (1990a) the congregations of western minnow in fast-flowing tributaries and considerations to the spawning conditions of similar eastern Australian species suggests that the western minnow may require fast-flowing streams to induce spawning. In lowland areas of the Swan Coastal Plain where populations are confined by a natural or man-made barrier (dams or v-notch weirs), the fish migrate into drainage channels and flooded riparian areas to spawn (Davies *et al*. 1996).

Morgan *et al.* (1996) suggested that habitat alteration and the introduction of exotic species may pose a threat to some populations of this species. Western minnow was absent/rare in streams which contained large numbers of mosquitofish and abundant in streams that did not contain mosquitofish (Morgan *et al*. 1996). Mosquitofish was observed attacking the western minnow (Morgan *et al*. 1996). Circumstantial evidence collected during the same study suggested that *Perca fluviatilis* and trout species may have an effect on native fish in dry years. Isolated pools with large introduced piscivores present contained very few native fish, whereas pools in which the introduced fish were absent, were abundant with native fish.

Nightfish (Bostockia porosa)

Family: Percicthyidae

This endemic freshwater fish ranges in colouration from mottled olive-brown to dark purplish-brown and occasionally black in peat stained waters. Studies of the distribution of nightfish have found it to be common and abundant throughout most of its range from Moore River to Albany in rivers, streams, lakes and pools. This species is typically found under ledges, rocks, logs and amongst inundated vegetation and was only present in open water when water levels had receded to such a point that no cover was available (Morgan *et al.* 1996). The few small larvae caught by Morgan et al (1996) were found in the relatively deep open water of a pool that was connected to a stream and in the shallow floodwaters of a large pool. Ostracods and dipteran larvae are important dietary requirements in all seasons although larger odonatan larvae, decapods and gastropods become important as the fish increase in size (Pen & Potter,1990b). Nightfish are typically active at night although recent studies showed that juveniles fed predominantly during the day. The life cycle of nightfish tends to last for two years, although a male of six years has been recorded. During summer and autumn, nightfish occupy the often disconnected deep pools, typical of the river during the dry season (Pen & Potter 1990b). In the same study, virtually all of the fish caught or observed during July to September were taken in tributary creeks rather than the main body of the river. Sexual maturity is reached at the end of the first year of life in males and the end of the second year of life in females. Spawning occurs on inundated vegetation and only once in a breeding season (Pen & Potter 1990b). Similarly to the western minnow, nightfish migrate to smaller tributaries during July, August and September with the onset of heavy winter rainfall. The results of Pen & Potter's (1990b) study indicated that no spawning took place until after July and that peak spawning occurred after water temperatures and daylight length started to increase after the winter solstice but while discharge was still high. Nightfish therefore spawn in a restricted period between August and mid-September and water flow in creeks is crucial for optimal spawning.

Similar to Western Minnow, Morgan *et al.* (1996) suggested that habitat alteration and the introduction of exotic species may pose a threat to local populations of nightfish. (Morgan *et al.* 1996) found that nightfish were absent/rare in lakes that had large numbers of mosquitofish but abundant in water bodies that did not contain this introduced species. Where mosquitofish was present in large numbers, nightfish also showed a high degree of fin damage, presumably as a result of being attacked by mosquitofish. However, the one-spot livebearer was recorded as the most dominant introduced species in the recent monitoring survey by Morgan et al 2007, this may be indicative of the early stage of transition, from one dominated by Eastern Mosquito fish to one that is dominated by One-spot Livebearers. Further ecological monitoring of this species within the Canning River would be required to determine this.

Western pygmy perch (Edelia *vittata*)

Family: Nannopercidae

The western pygmy perch is abundant and widespread in rivers, streams, lakes and pools between Moore River in the north and Philipps River, east of Albany (Morgan *et al*. 1996). According to a study of the fish in the South-west of Australia (Morgan *et al*. 1996), their habitat is described as generally associated with riparian vegetation and other forms of cover such as aquatic macrophytes, algae and snags. In the study it was rarely caught in open or deep water. Cladocerans, copepods and dipteran larvae are important dietary items as well as a wide range of small invertebrate prey types. The life cycle of western pygmy perch typically lasts just over two years. Sexual maturity is attained at the end of the first year of life and spawning occurs in flood waters of the main river and associated creeks between late July and November. Peak spawning times occur in late September/early October. This species spawns more than once in a breeding season.

Similarly to both western minnow and nightfish, Morgan *et al.* (1996) found that western pygmy perch tended to be rare or absent in waterbodies where mosquitofish was present and had a higher degree of fin damage. The only case where western pygmy perch was abundant when large number of mosquitofish were present, was in a waterbody containing dense cover of aquatic macrophytes and algae.

Freshwater cobbler (Tandanus bostocki)

Family: Plotosidae

Freshwater cobbler is the largest of the freshwater endemic fish species in the south-west of Western Australia and can live up to nine years. It is the only endemic species that is sought for recreational fishing and as a result has become an icon freshwater native fish for the Swan Coastal Plain and South-west region. It can be recognised by its large size and eel-like tail with brown to tan colouring and distinctive mottling on head, body and fins. It inhabits slow-flowing rivers and streams, isolated pools in riverbeds, reservoirs and freshwater lakes. It swims close to rocky, gravelly or sandy beds. The freshwater cobbler's diet is known to consist of insect larvae, freshwater shrimps, crayfish, molluscs and small fish. In Wungong Dam, the majority of fish do not become sexually mature until the end of their fourth year of life (Morgan *et al*. 1996). Breeding occurrs between November and January and is reported to require water temperatures between 20-24ºC. Males guard a nest under stones or among aquatic macrophytes where several females have laid their eggs. Freshwater cobbler 'nests' are at risk from unpredictable or unseasonal high flows, which may dislodge the nests downstream or from severe low flows which may result in desiccation and exposure of nests (Storey 2002). Habitat alteration may pose threats to some populations of this species (Morgan *et al*. 1996) and the freshwater cobbler was rarely recorded or absent in recent studies of the Canning and Southern-Wungong Rivers (Storey 1998, Wetland Research and Management 2000).

However, (Morgan *et al.* 2007) recorded two cobbler passing over the weir (September and November), prior to their breeding season, This study found little evidence of the structure impeding endemic fish migration during ‘higher flows’ for flows over the weir of 0.36m (June to July) and 0.2 m (AHD) (September to November). However, migration of the Freshwater Cobbler from November-January (Summer) may be impeded during low flow periods that create a vertical jump due to low tail-water levels. The limited number of recordings of this species is a cause for concern for the Canning and Southern-Wungong populations. Future flow regimes during summer spawning periods should aim to maintain flow over impoundments at a sufficient flow height and within ‘passable’ velocities to enable fish migration.

Native Species with Recent Marine origins

Swan River goby (Pseudogobius olorum)

Family: Gobiidae

The known distribution of the Swan River goby extends from Moore River in the north to Esperance in the south-east. The Swan River goby tends to occupy rivers, lakes and brackish estuaries and is usually found on mud or rock bottoms, sometimes among weeds (Allen *et al.* 2002). It tends to move into the lower freshwater reaches of rivers for extended periods (Storey 2000) In the Swan Estuary, algae and mats of bacteria and fungi are the major dietary components in spring, summer and winter, whereas a considerable amount of animal matter is consumed in winter (Morgan *et al*. 1996) although Fairhurst, (1993, cited Morgan *et al*. 1996) found that in lakes on the Swan Coastal Plain, the Swan River goby feeds predominantly on animal taxa in all seasons. This species can withstand extreme salinities and temperatures and is one of the few native species found in highly eutrophic systems.

Swan River hardyhead / Western hardyhead (Leptatherina wallacei)

Family: Atherinidae

Swan River hardyhead is abundant in the south-west of Australia and its range extends from Moore River in the north to Pallinup in the south (Morgan *et al*. 1996). It often forms large schools in estuaries, rivers, streams and lakes in the coastal areas throughout its range. In the Swan Estuary, important dietary items are planktonic crustaceans, flying insects, polychaetes and unicellular algae (Morgan *et al*. 1996). The Swan River hardyhead obtains sexual maturity at the end of its first year of life. Very few fish survive past their first year. The species has an extended spawning period that peaks in late spring.

Big-headed goby/ South Western Goby (Afurcagobius suppositus)

Family: Gobiidae

The big-headed goby is distributed between Moore River and Esperance and is found in lakes, estuaries, rivers, streams and coastal lakes (Morgan *et al*. 1996). The species has a strong preference for heavy cover (Gill & Humphries cited Morgan *et al.* 1996). Morgan *et al* (1996) cited Young (1994) who suggested that hemipterans and dipterans are important dietary components of the big-headed goby in all seasons, while bivalves, terrestrial insects, ephemopterans, trichopterans and teleosts are important in some seasons. Morgan *et al.* (1996) postulated that although the duration of the life cycle and the reproductive biology is unknown, the species probably lives for at least two years and is likely to breed at the end of its first year of life. A study conducted by Pusey *et al.* (1988) recorded the presence of big-headed goby as rare in the Canning River.

Introduced species

Mosquitofish/Gambusia (*Gambusia holbrooki*)

Family: Peociliidae

This species was introduced to Australia in the 1920's and to Western Australia in 1934 to control mosquitos (Morgan *et al*. 1996). Numbers are almost plague proportions in some rivers in the eastern states and it is now widely accepted that they had minimal effect on mosquitos and may even have exacerbated the problem due to their predation on natural invertebrate predators of mosquito larvae. In Western Australia, mosquitofish are widespread throughout the south-west and where present, are typically abundant (Morgan *et al*. 1996). It is considered a pest in many areas in the world because it occurs in high densities and competes with native species for food resources and habitat. Mosquitofish has the capability to rapidly increase in population size due to its reproductive characteristics. Sexual maturity is reached in a short time and fertilisation is internal, with females bearing live young. Spawning occurs when the water temperature is greater than 15ºC during spring, summer or autumn (Morgan *et al*. 1996).

The diet of mosquitofish is often dominated by terrestrial insects and at times by benthic organisms. It also ingests fish eggs and young fish. Pen *et al.* (1993b) classified the species as an opportunistic carnivore.

Mosquitofish are typically suited to lentic habitats including lakes, pools and slow flowing rivers. However, it readily invades seasonally inundated vegetation (Storey 1998). A study conducted by Pusey *et al.* (1988) on the Canning and North Dandalup rivers found that mosquito fish was most abundant in lentic habitats only. Where native fish co-occurred with mosquito fish, they were in low densities and usually confined to inlet streams. Native species were abundant in lotic systems only. Morgan *et al.* (1996) found a similar pattern: in waterbodies where mosquito fish was present, western pygmy perch, western minnow and nightfish were rare or absent. In contrast, rivers and streams where mosquito fish were absent, the same native species were typically abundant. The only waterbody where western pygmy perch was abundant when mosquito fish was present was in a lake containing large amounts of cover in the form of aquatic macrohytes and algae.

Mosquitofish tends to be either dominant, or the only species present in situations in which a diversity of resources no longer exist (Storey *et al*. 2002; Storey 2000b; Morgan *et al*. 1996). Pusey *et al.* (1988) suggested that the presence of mosquitofish in high numbers in the Canning River could be attributed to impoundment by the Canning Dam. The lower reaches of the river are characterised by slow-flowing water and deep pools, particularly in summer. This habitat is comparable to a lentic environment to which mosquitofish is typically suited. In contrast, the North Dandalup River is impounded by a pipehead dam, which overflows each winter making the system more prone to spates. The lower North Dandalup is also typically shallower and faster flowing. The presence of fewer mosquitofish could be due to reduced suitability for colonisation or may be because mosquitofish is not a particularly strong swimmer and cannot resist floodwaters.

As yet, there have been no successful management activities to reduce numbers of this species in south-western Australian wetlands (Storey *et al*. 2002).

Rainbow trout (Onocorhynchus mykiss)

Brown trout (Salmo trutta)

Family: Salmonidae

The rainbow trout can be found in rivers, streams, lakes and dams in the south-west region and are locally abundant in waterbodies that have been subject to continued stocking for recreational fishing (Morgan *et al*. 1996). Rainbow trout can reach a maximum size of 78cm (8kg) in Australia. They typically prefer lakes but can also be found in streams in cool (10 – 22ºC), well oxygenated water often over gravel bottoms. Morgan *et al.* (1996) stated that although there is likely some limited reproductive success in the south-west, trout populations are maintained by stocking of waterbodies with mainly hatchery reared fry and yearlings.

The brown trout can be found in rivers, streams, lakes and dams in the south-west of Western Australia but has not been as extensively stocked as rainbow trout. Brown trout can reach a maximum of 90cm (14kg) and inhabit cool, flowing streams where temperatures remain below 25ºC. Many self-sustaining populations have been established in the south-west (Allen *et al*. 2002). During winter they spawn in areas with gravel substrate. Their diet includes insects, crustaceans, molluscs, and small fish. Morgan & Gill (2000) noted that as summer flow reduced the river to a series of small pools, when either trout species were present native fish were usually absent.

Recent fish surveys of the Canning and Southern-Wungong systems have not recorded the presence of either trout species (Storey 1998; Wetland Research & Management 2000). This may suggest that populations in the Canning and Southern-Wungong Rivers are not self sustaining or are relatively small.

One spot livebearer/Speckled mosquitofish (Phalloceros caudimaculatus)

Family: Poeciliidae

This species is similar in appearance to mosquitofish. Females grow to 6cm, males to 2.5cm. They have an extremely protracted breeding period and can occur in extreamily high abundances, specifically in Bull Creek (Madden 2003, Morgan & Beatty 2006a). Previously, Morgan & Beatty (2006) reported that 'relatively few populations exist in swamps and drains of Perth metropolitan area' and none were reported within the Canning System. However, the One-spot Livebearer dominated catches during the Seaforth (616027) fish monitoring period, when “juveniles’ were moving downstream during June and July 2006. The dominance of this species to the occlusion of the Eastern Mosquitofish is unclear. The One-spot Livebearer appears to have some form of competitive advantage, such as early maturation, prolonged breeding period, non-specialised diet or potential hybridisation. The dominance of this species over the Eastern Mosquitofish within the recent study may be indicative of an early stage of a system that is dominated by Eastern Mosquitofish to one that is dominated by One-spot Livebearers (Morgan *et al.* 2007).

Carp/Goldfish (Crassius auratus)

Family: Cyprinidae

Goldfish were introduced into Australia in 1876 and are now widely distributed in streams, ponds, and dams throughout the southern half of Australia. Those found in Australia are typically silvery/greyish or bronzy, unlike the aquarium varieties and they are normally less than 0.5 kg. Goldfish inhabit still or slow-flowing water such as backwaters of rivers, swamps and lakes. It is able to withstand high summer temperatures and low oxygen concentrations. Organic detritus, plant matter and aquatic insects are the major dietary components (Allen 2002). Very little is known of the life history, ecology, dietary requirements or reproductive cycle of goldfish in south-western Western Australia (Storey 1998). Goldfish may also add to the increased nutrient levels within pools and exacerbate anoxic conditions.

Appendix B — Hydrology of the Canning River

Report prepared by Mr Mark Pearcey, Surface Water Hydrology, Water & Rivers Commission

Introduction

The Canning River flows in a northwesterly direction to Canning Reservoir. Construction of Canning Dam was completed in 1940 with a catchment area of 754 km^2. Kangaroo Gully naturally connects into the Canning River downstream of the dam, however a diversion channel from Kangaroo Gully into Canning Dam was constructed in 1951. The full supply storage capacity of Canning Dam is 90 Mm^3.

Rainfall

There is a distinct rainfall gradient across the Canning Dam catchment, ranging from 1250 mm at the reservoir to 700 mm in the eastern portion of the catchment. The rainfall is highly seasonal with 80% of the rainfall occurring between May and September, inclusive (Figure B-1).

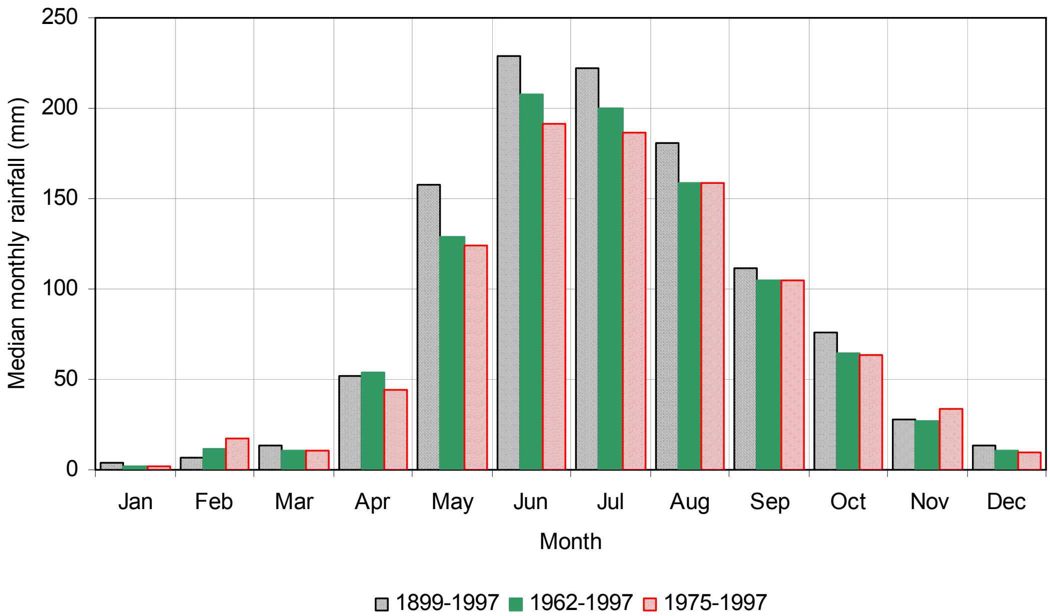

Figure B-1: Median monthly rainfall Armadale-Canning River Weir (009 050)

Rainfall in the southwest of Western Australia since 1975 has generally been lower than the long term mean and this is also apparent in the Canning River catchment (Figure B- 2). Figure B- 2 shows the annual rainfall recorded at Armadale-Canning River Weir for a range of climatic periods.

Table B- 1. Annual rainfall statistics for Armadale - Canning River Weir (009 050)

	1899-1998	1912-1997	1962-1997	1975-1997
Mean (mm)	1215	1231	1097	1012
10 percentile (mm)	880	884	849	847
50 percentile (mm)	1165	1171	1062	1016
90 percentile (mm)	1583	1624	1410	1162
Standard deviation (mm)	285	294	223	137
Coefficient of Variation	0.23	0.24	0.20	0.14

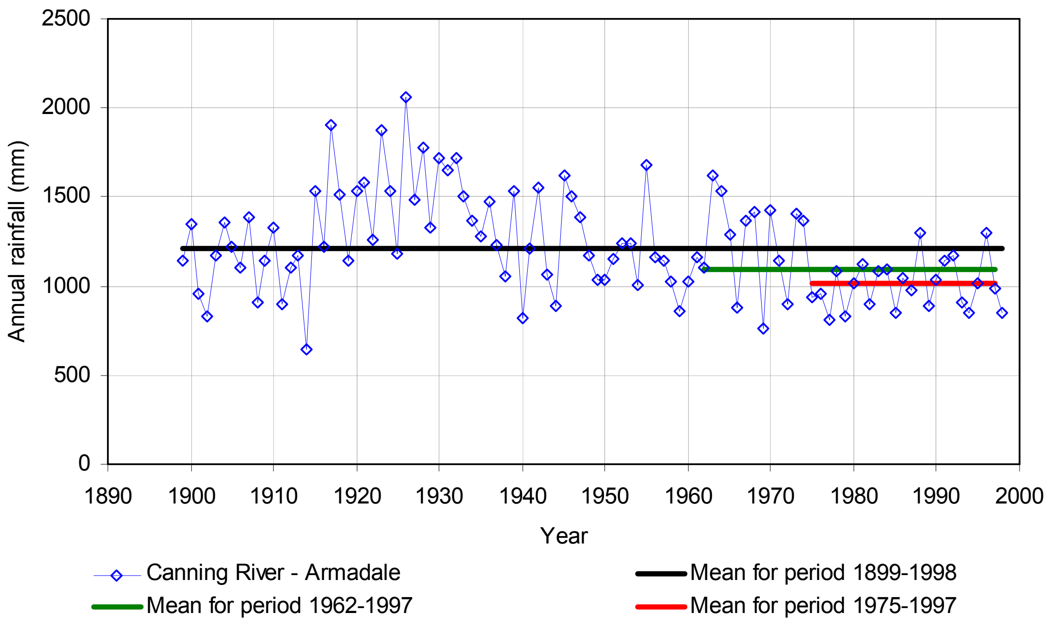

Figure B- 2: Annual rainfall at Armadale - Canning River Weir (009 050)

Streamflow

Construction of Canning Dam was completed in 1940. A streamflow gauging station was operated at the dam site from 1908 until construction commenced in 1934. After 1934 the inflow into Canning Reservoir has been estimated from a monthly water balance.

The streamflow in the Canning River is highly seasonal with 93% occurring between June and October (Figure B- 3). This seasonality is due to the seasonality of the rainfall and evaporation but is exaggerated by the soils and vegetation in the catchment.

Figure B- 4 shows the annual inflow data for Canning Reservoir while Table B- 2 details the basic statistics on Canning Reservoir inflows for different periods of record. This data shows the reduced mean annual streamflow in recent years that is evident in much of the southwest of Western Australia. However, while the mean annual rainfall for 1975-1997 is 82% of the mean annual rainfall for 1912-1997, the mean annual streamflow for 1975-1997 is 51% of the mean annual streamflow for 1912-1997.

Table B- 2. Annual Canning Reservoir inflows statistics

	1912-1997	1962-1997	1975-1997
Mean (Mm^3)	55.3	47.0	28.4
10 percentile (Mm^3)	16.0	14.2	12.6
50 percentile (Mm^3)	39.5	36.8	21.0
90 percentile (Mm^3)	107.2	97.3	53.8
Standard deviation (Mm^3)	42.5	39.8	15.6
Coefficient of Variation	0.77	0.85	0.55

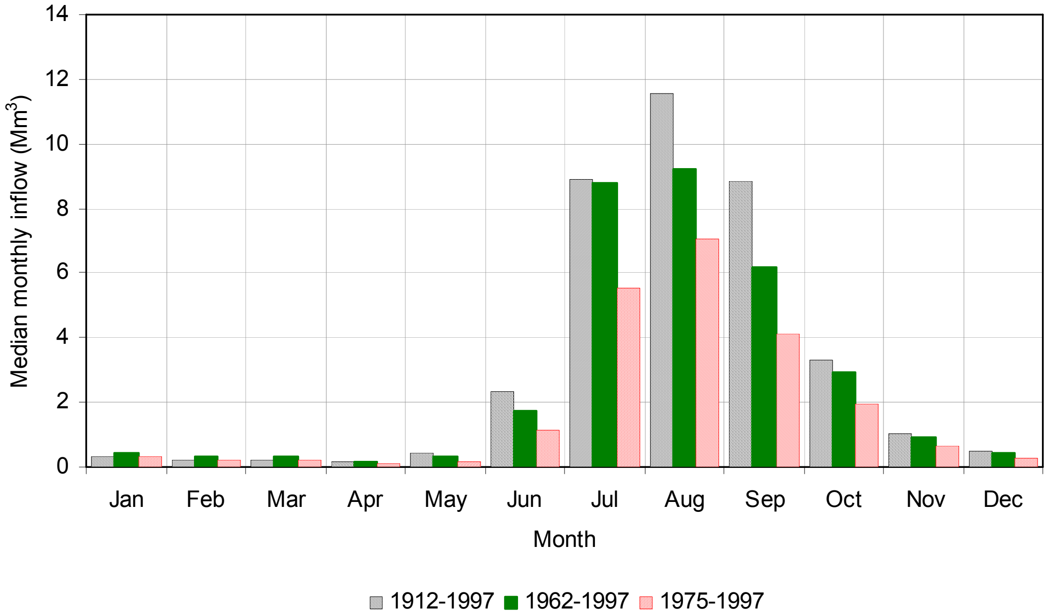

Figure B- 3: Median monthly inflow to Canning Reservoir

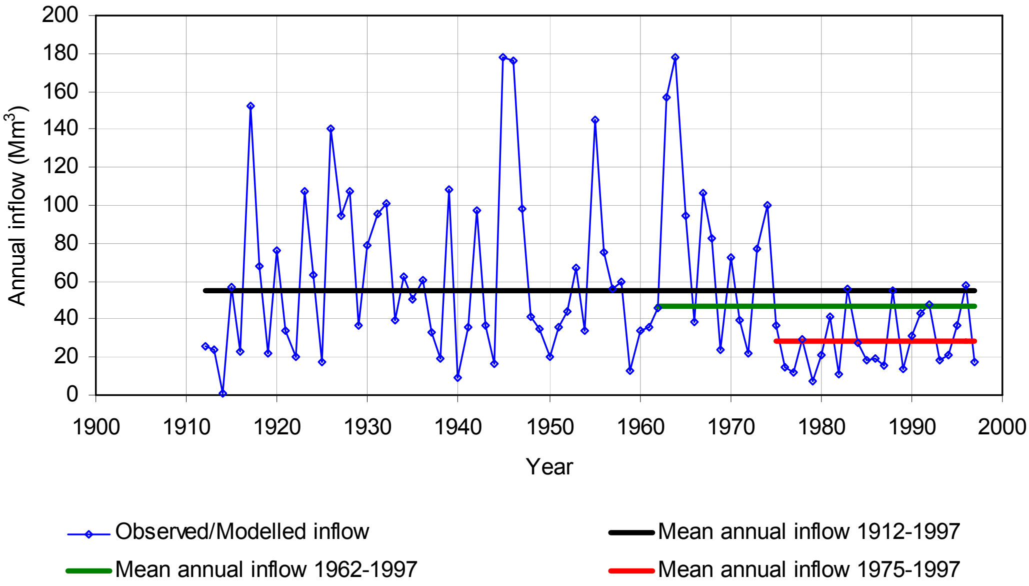

Figure B- 4 Annual inflow to Canning Reservoir

While there has been a significant reduction in the mean annual flow in recent years, it has not been a uniform reduction in all months. The summer flows (December to April inclusive) in the Canning River for the period 1975-1997 have only exhibited a minor reduction compared with the mean summer flow for the period 1912-1997 (Table B- 3), although the reason for this sustaining of summer flows is unclear.

Table B- 3: Comparison of Canning Reservoir summer inflows

	1912-1997	1962-1997	1975-1997
Mean summer flow (Mm^3)	1.8	2.0	1.5
Mean annual flow (Mm^3)	55.3	47.0	28.4
Summer flow as a % of mean annual flow	3.2	4.3	5.3

Canning River-Seaforth (616027)

The Seaforth gauging station on the Canning River (616027), approximately 15 km downstream of Canning Dam, records flow from the 138 km^2 catchment below the Canning Dam and all overflows and releases from the reservoir. The gauging station was originally constructed in 1974 as Canning River at Mackenzie Grove.

Flow Data Extension

While the Seaforth gauging station records overflows from Canning Dam, there have been no overflows since 1975. As such, the flow recorded at the Seaforth gauging station is a combination of the flow from the catchment downstream of the dam and releases from the reservoir. Reservoir releases have not been recorded continuously but some data is available from 1995/96 to 1999/00. Environmental releases have typically only occurred from October to May. From the limited available recorded data the monthly environmental release from October to May, inclusive, is a maximum of 0.1 Mm^3. This value was used to estimate the natural flow at the Seaforth gauging station downstream of Canning Dam.

A good correlation between the Canning Dam inflows and the natural flow at the Seaforth gauging station existed so the Canning Dam annual inflow data was used to calculate the Matalas-Jacobs augmented mean annual flow (1962-1995) for Seaforth gauging station, downstream of Canning Dam (Table B- 4).

Table B- 4: Comparison of the Canning Dam and Seaforth catchments

	Canning Dam	Canning River Seaforth 616027	Canning River Seaforth (D/S of Canning Dam)
Catchment area (km^2)	754	892	138
Mean annual rainfall (mm)	900	1000	1275
Clearing (%)	0	5	20
Mean annual flow 1962-95 (Mm^3)	47.5	-	19.2
Mean annual flow 1962-95 (mm)	63	-	139

A regional relationship (REG6) was used to determine calibration factors for the Seaforth mean annual flow. The regional relationship calculates the mean annual flow for the period 1962-1995 based on the catchment area, mean annual rainfall for the catchment and the level of clearing.

Pre-European Settlement Conditions

The major changes in the Seaforth catchment over the last 200 years that have impacted the hydrology are the flow regulation resulting from the construction of Canning Dam, and the clearing of 20% of the catchment.

The regional relationship (REG6) was used in conjunction with the Canning Dam inflow data to estimate the flow at Seaforth under pre-European settlement conditions.

Results

The estimated mean annual flow (1962-1995) for pre-European settlement conditions at Seaforth gauging station is 62.4 Mm^3 compared with the existing estimated mean annual flow (1962-1995) of 19.2 Mm^3.

The change in mean monthly flows from pre-European settlement conditions to existing conditions are shown in Table B- 5 and Figure B- 5.

Table B- 5: Mean monthly flows (Mm^3) at Canning River-Seaforth (616027)

	Canning River – Seaforth (616027) Pre-European conditions		Canning River – Seaforth (616027) Existing conditions[1]		Canning River – Seaforth (616027) Existing conditions-No environmental release[2]	
	1962-1995	1975-1995	1962-1995	1975-1995	1962-1995	1975-1995
January	0.62	0.51	0.25	0.18	0.15	0.09
February	0.51	0.41	0.28	0.27	0.18	0.18
March	0.47	0.39	0.24	0.23	0.14	0.13
April	0.46	0.50	0.29	0.33	0.19	0.23
May	0.91	0.77	0.59	0.73	0.49	0.63
June	6.52	3.15	2.32	1.89	2.32	1.89
July	15.96	8.96	4.75	3.24	4.75	3.24
August	17.74	10.98	4.80	3.24	4.80	3.24
September	10.85	7.43	2.85	1.96	2.85	1.96
October	6.05	3.59	1.80	1.23	1.70	1.13
November	1.63	1.08	0.62	0.53	0.52	0.43
December	0.66	0.39	0.28	0.21	0.18	0.12

1. This is the mean of the observed flow including all environmental releases from Canning Dam.
2. This is the mean of the observed flow minus the estimated environmental releases from Canning Dam.

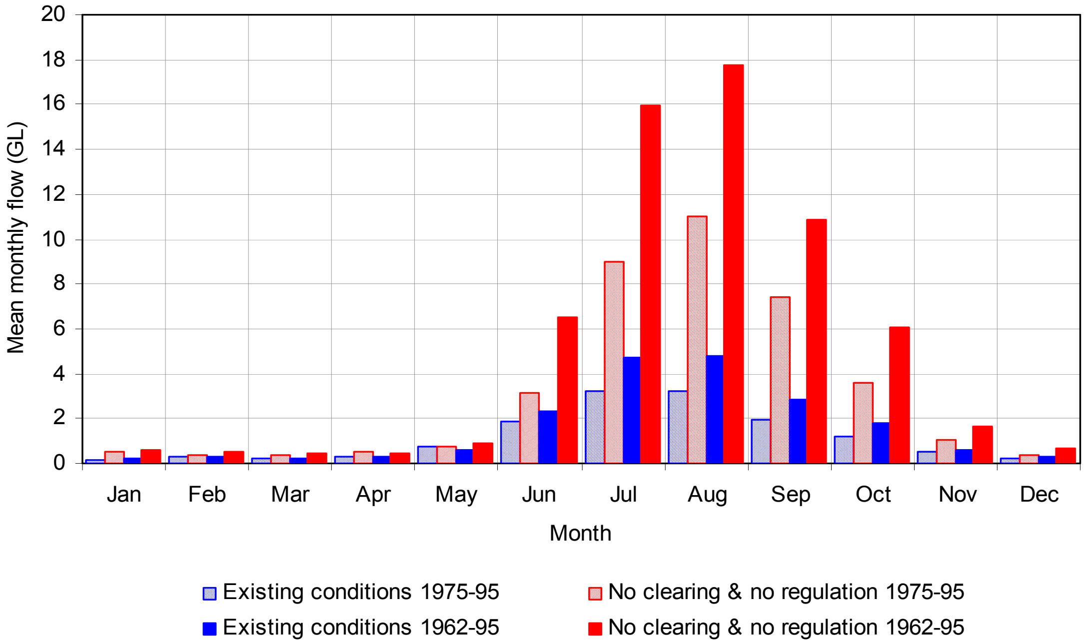

Figure B- 5: Mean monthly flows at Canning River - Seaforth (616027)

Appendix C — Means, medians, percentiles & frequency of flows

Table B-6. 616153 Kargotich, Wungong Brook pre-dam (1961-1975) (ML)

Month	n	mean	median	pctl10	pctl20	pctl30	pctl40	pctl50	pctl60	pctl70	pctl80	pctl90
Jan	11	130.84	95.22	64.16	70.83	77.49	78.58	95.22	123.74	125.28	183.01	238.73
Feb	10	140.84	109.26	57.33	68.06	79.65	91.26	109.26	136.52	173.6	202.88	284.37
Mar	10	236.52	168.09	64.03	88.08	122.76	134.38	168.09	219.27	284.01	348.73	543.74
Apr	10	412.93	409.37	54.28	157.62	303.28	364.65	409.37	450.34	456.44	489.3	841.27
May	11	933.04	755.71	399.06	516.22	683.58	690.92	755.71	771.41	1199.1	1370.91	1468.37
Jun	11	5162.2	4876.43	1163.03	1763.24	2897.57	3771.43	4876.43	6437.84	6438.77	8212.97	10278.9
Jul	11	6544.24	5662.11	2143.6	2809.17	3238.29	5119.46	5662.11	6428.87	7053.48	9936.9	11898.64
Aug	11	6564.59	3879.77	2623.42	2749.67	3591.78	3644.76	3879.77	8230.78	8282.16	8920	12275.5
Sep	10	3544.97	2928.65	1437.92	2314.55	2443.99	2712.24	2928.65	3973.08	5119.54	5444.52	5794.77
Oct	10	3012.13	2743.26	333.03	564.54	883.38	1498	2743.26	4137.46	4801.3	5578.49	6299.68
Nov	11	769.99	362.78	83.01	96.2	200.8	278.94	362.78	406.91	611.02	995.63	1974.92
Dec	11	228.97	162.19	74.33	110.29	136.82	143.25	162.19	188.48	253.06	318.46	407.92

mean annual discharge	27768.09	n = 9
median anuual discharge	26958.07	

Table B-7. 616153 Kargotich, Wungong Brook post-dam (1977-1996) (ML)

Month	n	mean	median	pctl10	pctl20	pctl30	pctl40	pctl50	pctl60	pctl70	pctl80	pctl90
Jan	20	46.598	29.283	9.911	13.466	21.37	25.452	29.283	34.509	49.548	61.423	125.32
Feb	20	53.166	31.783	4.265	5.714	8.713	22.644	31.783	42.024	50.836	91.552	153.2
Mar	20	48.919	29.621	7.436	9.362	12.96	25.129	29.621	38.119	50.431	61.717	118.79
Apr	20	51.099	35.123	6.896	11.126	17.47	24.983	35.123	41.126	45.568	79.793	127.44
May	20	113.613	70.458	27.866	41.215	50.363	58.957	70.458	78.656	92.28	155.796	355.78
Jun	19	320.003	217.768	89.681	115.614	170.119	174.142	217.768	238.196	339.447	480.962	969.23
Jul	19	837.85	361.414	194.14	282.15	292.831	319.545	361.414	446.954	515.803	614.947	1677.97
Aug	19	573.749	344.059	191.491	225.82	236.423	276.852	344.059	374.963	449.772	509.962	1054.25
Sep	19	326.963	209.877	105.214	131.559	170.295	206.825	209.877	236.618	332.898	367.735	445.85
Oct	19	291.145	131.998	58.35	78.614	94.263	102.783	131.998	145.745	152.459	274.602	1042.67
Nov	19	78.731	73.84	35.131	47.18	52.622	62.964	73.84	84.108	100.879	109.049	134.67
Dec	19	55.657	49.892	26.074	30.297	35.747	36.978	49.892	53.686	62.144	63.889	96.48

mean annual discharge	2809.96	n = 19
median anuual discharge	1718.25	

Table B-8. 616041 Vardi Road, Wungong Brook, upstream from Wungong Dam (1981-1999) (ML)

Month	n	mean	median	pctl10	pctl20	pctl30	pctl40	pctl50	pctl60	pctl70	pctl80	pctl90
Jan	18	135.32	107.81	56.41	60.17	69.33	87.43	107.81	125.02	176.77	203.61	219.19
Feb	18	82.54	58.16	27.19	31.84	49.03	57.72	58.16	67.36	75.18	112.93	175.43
Mar	18	73.17	54.93	28.84	37.7	44.21	51.75	54.93	61.67	82.72	101.22	176.85
Apr	18	96.36	73.03	39.34	44.63	50.66	65.04	73.03	99.13	112.54	123	161.99
May	19	259.97	225.65	70.74	77.03	148.83	186.46	225.65	287.03	343.3	384.59	397.23
Jun	18	1128.93	783.09	431.41	469.46	704.94	733.17	783.09	988.11	1378.28	1664.49	2333.02
Jul	18	2458.81	2626.87	846.74	1275.43	1588.98	1776.49	2626.87	2946.34	3526.11	3625.66	4031.24
Aug	17	3114.22	2881.94	1550.15	2040.6	2463.61	2686.31	2881.94	3004.63	3188.67	4520.83	5262.67
Sep	17	2505.37	2166.22	1271.63	1514.95	1765.62	1819.07	2166.22	2485.88	2618.69	3305.51	4365.75
Oct	18	1464.04	1266.04	639.05	741.12	1158.12	1196.46	1266.04	1351.96	1519.39	2065.31	2944.2
Nov	18	758.38	675.57	323.4	387.31	453.13	539.21	675.57	718.98	943.14	1219.22	1452.05
Dec	18	298.45	275.21	153.96	157.28	177.25	189.65	275.21	288.77	411.39	475.09	534.66

mean annual discharge	12004.75	n = 16
median annual discharge	9769.77	

Table B-9. 616071 Pipehead Dam, Wungong brook, downstream from Wungong Dam (pre-dam 1911 - 1975) (ML)

Month	n	mean	median	pctl10	pctl20	pctl30	pctl40	pctl50	pctl60	pctl70	pctl80	pctl90
Jan	24	327.73	271.56	29.34	137.66	194.46	233.3	271.56	365.09	484.01	512.04	551.05
Feb	24	190.38	157.9	26.96	56.09	130.44	146.56	157.9	183.88	211.05	270.43	353.23
Mar	24	177.57	148.42	37.56	54.11	100.81	106.12	148.42	165.34	207.72	327.36	387.82
Apr	24	332.65	240.73	84.78	125.23	168.54	190.08	240.73	375.65	399.88	487.02	639.51
May	24	838.18	649.85	253.36	384.28	548.52	569.71	649.85	810.68	875.53	1144.96	1593.68
Jun	25	4124.76	3909.25	790.46	1544.99	1892.52	2174.53	3909.25	4196.05	4528.36	7438.78	8603.94
Jul	25	6877.39	5402.45	2514.45	3783.03	4458.59	4621	5402.45	6810.53	8946.76	11975.57	13174.32
Aug	25	7539.51	5355.69	3687.82	4190.36	4887.47	5181.21	5355.69	7261.02	8075.21	9424.77	13744.2
Sep	25	4247.54	3735.44	1547.81	2048.12	3059.84	3584.32	3735.44	4177.31	4953.84	6283.69	7822.96
Oct	25	3403.79	2552.79	1075.93	1569.28	1875.15	2199.94	2552.79	3112.1	4153.45	5260.49	5881.11
Nov	25	1374.19	1012.85	382.42	502.87	777.2	903.37	1012.85	1412.71	1543.74	1916.92	2775.15
Dec	25	649.34	505.63	117.81	205.61	427.29	460.47	505.63	774.33	807.11	935.66	1199.21

mean annual discharge	32239.04	n = 21
median annual discharge	29756	

Table B-10. 616092 Anaconda Drive, Southern River, post- Wungong Dam (1997 – 1998) (ML)

Month	n	mean	median	pctl10	pctl20	pctl30	pctl40	pctl50	pctl60	pctl70	pctl80	pctl90
Jan	1	133.39	133.39	133.39	133.39	133.39	133.39	133.39	133.39	133.39	133.39	133.39
Feb	1	89.42	89.42	89.42	89.42	89.42	89.42	89.42	89.42	89.42	89.42	89.42
Mar	2	238.79	238.79	172.6	172.6	172.6	172.6	238.79	304.98	304.98	304.98	304.98
Apr	2	393.38	393.38	167.44	167.44	167.44	167.44	393.38	619.31	619.31	619.31	619.31
May	2	500.87	500.87	357.64	357.64	357.64	357.64	500.87	644.1	644.1	644.1	644.1
Jun	2	1542.83	1542.83	1311.67	1311.67	1311.67	1311.67	1542.83	1773.99	1773.99	1773.99	1773.99
Jul	2	1141.65	1141.65	1016.92	1016.92	1016.92	1016.92	1141.65	1266.39	1266.39	1266.39	1266.39
Aug	2	2645.01	2645.01	2159.64	2159.64	2159.64	2159.64	2645.01	3130.39	3130.39	3130.39	3130.39
Sep	2	2488.38	2488.38	2353.6	2353.6	2353.6	2353.6	2488.38	2623.15	2623.15	2623.15	2623.15
Oct	2	830.66	830.66	716.73	716.73	716.73	716.73	830.66	944.6	944.6	944.6	944.6
Nov	2	213.07	213.07	36.35	36.35	36.35	36.35	213.07	389.8	389.8	389.8	389.8
Dec	1	266.63	266.63	266.63	266.63	266.63	266.63	266.63	266.63	266.63	266.63	266.63

Total annual flow 1.4.97 - 31.3.98:	11688.72
Total annual flow 1.11.97 - 31.10.98:	9765.28

Table B-11. 616027 Harry Hunter Stage, Canning River (1974-1998) (ML)

Month	n	mean	median	pctl10	pctl20	pctl30	pctl40	pctl50	pctl60	pctl70	pctl80	pctl90
Jan	24	195.73	148.52	62.95	78.92	90.89	126.88	148.52	197.46	222.3	266.6	399.88
Feb	23	249.34	161.12	68.99	79.1	110.28	139.26	161.12	179.45	251.49	303.64	396.59
Mar	23	237.06	209.73	91.12	121.74	148.67	206.88	209.73	234.65	294.86	308.39	347.21
Apr	23	310.84	309.3	148.68	189.59	252.45	297.61	309.3	328.06	369.15	398.43	474.54
May	24	744.32	683.93	356.59	389.57	546	617.02	683.93	732.51	867.81	974.41	1365.53
Jun	24	1910.86	1964.49	806.49	1002.66	1257.97	1625.46	1964.49	2099.08	2215.94	2460.17	2887.88
Jul	25	3031.24	3069.52	1129.54	1575.45	2029.8	2562.1	3069.52	3379.65	3789.92	4233.82	4998.65
Aug	25	4338.33	3208.36	1703.8	2459.19	2809.08	2984.21	3208.36	3460.43	3633.99	4150.1	4529.43
Sep	25	2386.99	1886.45	1348.62	1409.39	1527.24	1740.54	1886.45	1982.99	2904.07	3219.11	3744.65
Oct	25	1473	1083.85	736.47	789.27	907.01	959.28	1083.85	1264.85	1427.63	1539.77	2305.61
Nov	25	558.45	466.87	258.2	300.52	339.19	424.38	466.87	514.06	608.77	743.24	993.22
Dec	24	243.66	150.82	81.21	111.43	120.17	126.54	150.82	227.05	269.11	405.43	474.75

mean annual discharge	13954.97	n = 23
median annual discharge	14027.04	

Table B-12. 616031 Araluen, Canning River (1977-1995) (ML)

Month	n	mean	median	pctl10	pctl20	pctl30	pctl40	pctl50	pctl60	pctl70	pctl80	pctl90
Jan	14	8.30	2.80	0	0.02	2.29	2.40	2.80	4.94	6.84	21.46	26.17
Feb	15	12.15	2.76	0	0	0	0.19	2.76	5.74	19.28	30.57	34.73
Mar	15	8.13	1.19	0	0	0	0.23	1.19	3.47	6.23	21.44	30.38
Apr	15	25.96	5.24	0	0.96	2.38	4.99	5.24	20.14	23.07	30.27	55.39
May	16	56.29	55.86	0.38	30.11	38.57	49.38	55.86	58.30	76.73	80.09	104.86
Jun	16	177.12	149.92	71.35	101.54	105.19	134.00	149.92	156.58	207.49	212.94	368.30
Jul	16	375.68	304.09	116.56	138.13	157.80	257.32	304.09	343.56	427.58	503.87	646.02
Aug	16	271.29	249.54	59.78	147.00	166.90	217.34	249.54	309.22	376.26	383.46	416.46
Sep	14	195.88	142.85	35.51	47.01	89.34	110.62	142.85	184.07	254.26	420.05	456.50
Oct	14	115.38	79.37	33.01	40.91	51.00	72.66	79.37	100.93	111.02	188.04	311.37
Nov	15	51.24	48.66	15.58	25.11	29.67	30.72	48.66	50.94	53.64	83.91	91.36
Dec	15	19.52	18.75	1.77	7.64	8.82	12.37	18.75	20.92	25.98	31.84	42.50

mean annual discharge	1271.94	n = 14
median annual discharge	1165.54	

Table B-13. 616065 Glen Eagle, upstream of Canning Dam (1953 - 1975) (ML)

Month	n	mean	median	pctl10	pctl20	pctl30	pctl40	pctl50	pctl60	pctl70	pctl80	pctl90
Jan	43	12	0	0	0	0	0	0	0.06	0.48	2.41	19.99
Feb	40	1.33	0	0	0	0	0	0	0	0	0.13	1.99
Mar	40	0.54	0	0	0	0	0	0	0	0	0	0.46
Apr	42	4.82	0	0	0	0	0	0	0	0	0.06	6.21
May	44	53.53	0.01	0	0	0	0	0.01	5.9	14.6	70.67	170.18
Jun	45	1537.92	314.59	8.66	63.18	127.93	174.82	314.59	625.49	1462.92	2773.37	5203.26
Jul	45	4925.17	3749.65	224.3	736.38	1531.78	2914.58	3749.65	4310.58	5499.7	6850.84	9568.86
Aug	45	6186.06	4616.91	1360.51	2350.76	2825.97	3499.09	4616.91	5831.74	7211.06	9813.7	11501.37
Sep	46	3768.16	2692.66	696.38	1405.13	1655.03	2303.24	2692.66	3222.22	4282.13	5114.79	8374.32
Oct	45	2100.25	1330.37	261.6	492.37	655.26	938.33	1330.37	1478.05	2281.39	3238.62	5890.61
Nov	45	406.74	240.32	39.28	51.92	76.78	175.96	240.32	286.29	446.39	677.15	948.68
Dec	45	55.55	14.74	0.04	0.71	2.02	9.56	14.74	27.88	42.91	65.91	173.56

mean annual discharge	18540.95	n = 35
median annual discharge	13220.41	

Table B-14. 616066 Kangaroo Gully Diversion Channel (1985 – 1995) (ML).

Month	n	mean	median	pctl10	pctl20	pctl30	pctl40	pctl50	pctl60	pctl70	pctl80	pctl90
Jan	10	0.20	0	0	0	0	0	0	0.02	0.13	0.54	0.89
Feb	10	0.46	0.16	0	0	0.03	0.07	0.16	0.53	0.92	1.11	1.21
Mar	10	0.20	0.01	0	0	0	0	0.01	0.04	0.16	0.53	0.82
Apr	10	0.47	0.11	0	0	0	0.02	0.11	0.50	0.99	1.17	1.24
May	11	1.62	1.55	0.64	0.76	0.86	1.19	1.55	1.85	2.07	2.07	2.75
Jun	11	169.03	39.41	1.40	1.49	2.47	19.72	39.41	74.14	98.75	356.97	420.39
Jul	11	753.93	785.28	134.76	262.83	392.89	564.78	785.28	845.77	989.70	1350.53	1369.11
Aug	11	1137.18	976.52	700.62	773.15	930.71	941.96	976.52	1065.23	1173.14	1364.82	1519.60
Sep	11	650.01	465.22	315.53	344.41	350.47	383.48	465.22	581.89	881.65	910.73	1123.85
Oct	11	376.04	345.13	90.82	155.41	232.85	249.05	345.13	356.24	360.78	466.13	508.79
Nov	11	89.76	55.31	16.35	19.98	31.59	49.67	55.31	67.23	94.76	163.04	172.81
Dec	11	4.28	0.51	0	0	0	0.13	0.51	3.20	4.13	9.19	9.49

mean annual discharge	3183.05	n = 11
median annual discharge	2491	

Table B-15. 616067 Kangaro Gully (1908 - 1951) (ML)

Month	n	mean	median	pctl 10	pctl 20	pctl 30	pctl 40	pctl 50	pctl 60	pctl 70	pctl 80	pctl 90
Jan	42	5.76	0	0	0	0	0	0	0	1.75	3.40	19.67
Feb	42	1.44	0	0	0	0	0	0	0	0	0	0
Mar	42	2.37	0	0	0	0	0	0	0	0	0	0
Apr	42	8.91	0	0	0	0	0	0	0	0	1.94	30.34
May	44	129.70	40.70	0	3.66	6.54	16.54	40.70	58.76	89.17	260.40	435.90
Jun	43	758.85	352.00	79.44	135.80	213.00	295.60	352.00	640.40	776.60	1366.00	1868.00
Jul	43	1774.21	1310.00	384.80	659.80	717.80	1079.60	1310.00	1652.00	2118.00	2572.00	3912.00
Aug	43	1986.37	1780.00	552.80	942.00	1296.00	1480.00	1780.00	1916.00	2512.00	3230.00	3460.00
Sep	44	1473.10	1425.00	438.20	507.00	627.20	1058.00	1425.00	1612.00	1729.00	2154.00	2853.00
Oct	44	764.69	599.50	205.20	338.80	403.80	485.00	599.50	678.00	860.10	1036.00	1476.00
Nov	44	219.48	149.50	28.62	48.34	107.46	129.40	149.50	224.40	281.70	330.60	406.70
Dec	44	40.18	20.65	1.54	3.30	7.00	14.26	20.65	26.94	39.81	67.06	82.28

mean annual discharge	7,061.55	n = 44
median annual discharge	6,307.00	

Appendix D — Water quality data

Table D- 1. Canning catchment water quality data monitored by Water & Rivers Commission (WRC) and Water Corporation (WC).

Parameter	Harry Hunter (WRC) 1974-1999		Kent Street (WRC) May 1998		Anaconda Drive (WRC) limited data 1996-1999		Araluen (WC; 616031) 1977-1995		Wungong (WC; 613153) 1962-1994	
	median	range	median	range	median	range	median	range	median	range
Chl-a (mg/L)	0	0	-	-	-	-	-	-	-	-
Colour (Hazen)	15	5-250	0	-	66	66 - 74	13.5	5-30	13	5-39
DO (mg/L)	7.4	6-9.5	-	-	8.7	-	-	-	-	-
DO (%)	81	69-93	-	-	-	-	-	-	-	-
Econd. (mS)	61.8	24.1-213	48.9	-	39.7	39.1-87	41.5	28.7-119.1	-	-
pH	-	-	7.19	-	7.4	-	6.7	5.3-7.8	7.1	5.9-8.5
Discharge (m3/sec)	0.44	0-43.4		-	0.57	0.31-1.63	-	-	-	-
Stage-SL (m)	10.28	9.8-13.5	11.4	-	10.52	10.15-11.0	10.2	10.02-11	10.3	10.05-11.2
NH3 (mg/L)	0.04	0.02-0.11	-	-	0.1	-	-	-	-	-
NO3/NO2 (mg/L)	5	1-11	-	-	-	0.21 & 0.33	< 1	-	7	2-42
TN (mg/L)	0.68	0.56-0.80	-	-	-	0.86 & 1.01	-	-	-	-
TP (mg/L)	0.02	0.01-0.14	-	-	-	0.03 & 0.19	-	-	-	-

Parameter	Harry Hunter (WRC) 1974-1999		Kent Street (WRC) May 1998		Anaconda Drive (WRC) limited data 1996-1999		Araluen (WC; 616031) 1977-1995		Wungong (WC; 613153) 1962-1994	
	median	range	median	range	median	range	median	range	median	range
SO4 (mg/L)	26	14-45	-	-	-	-	18	13-25	23	18-26
TDS (mg/L)	392	250-498	-	-	-	-	-	-	-	-
TSS (mg/L)	323	176-737	-	-	-	-	-	-	-	-
Turbid (NTU)	510	1-110	7.3	-	5.1	-	2.1	0.8-9.4	5.05	1-120
Temp. (C)	15	10-25	19.2	-	22.9	-	13.6	8.3-27.7	15.5	7.7-28

Table D- 2. Water quality data for the Lower Canning catchment (Storey 1999) and Southern Wungong catchments (Storey 2000).

Site	Date	Name	Conductivity us/cm	Chloro_a mg/L	Chloro_b mg/L	Chloro_c mg/L	Phaeo_a mg/L	Colour TCU	Turbidity NTU	N_NH3 mg/L	N_NO3 mg/L	N_total mg/L	P_SR mg/L	P_total mg/L
Canning														
LC4	Feb-99	Stocker Road, Roleystone	345	0.001	-	-	0.001	27	52	0.02	0.06	0.67	0.03	0.05
LC4C	Feb-99	Canning River @ Brookton Hwy	328	0.002	-	-	0.001	16	24	0.02	<0.02	0.56	0.01	0.03
LC3	Feb-99	Below Stinton Ck/Canning R. confl.	355	0.001	-	-	<0.001	8	0.6	<0.02	<0.02	0.29	<0.01	0.01
LC7A	Feb-99	O'Dell Street	871	0.009	-	-	<0.001	77	3	0.02	<0.02	0.64	0.08	0.11
LC6	Feb-99	Manning Avenue	647	<0.001	-	-	0.005	25	2.5	0.08	0.06	0.68	<0.01	0.02
LC6A	Feb-99	Lissiman Street, Gosnells	533	<0.001	-	-	0.007	<5	6.5	0.21	0.03	0.57	<0.01	0.02
LC7	Feb-99	Burslem Drive, Maddington	756	<0.001	-	-	0.006	61	3	0.07	0.13	0.82	<0.01	0.07
LC1	Feb-99	Between Canning Dam & Araluen	349	<0.001	-	-	<0.001	47	2.6	0.03	0.02	0.44	<0.01	0.01
CD6	Feb-99	31 Mile Ck-Above v-notch weir on ck	689	<0.001	-	-	<0.001	8	0.3	0.02	<0.02	0.22	0.01	0.01
SC3	Feb-99	Stinton Ck-Above small weir on ck	348	<0.001	-	-	<0.001	9	0.5	<0.02	0.02	0.27	<0.01	0.01
LC1A	Feb-99	Between Canning Dam & Araluen	380	-	-	-	-	27	2.7	<0.02	<0.02	0.34	<0.01	0.01
Wungong Brook														
WB 1	Mar-00	Wungong Bk 3 km E of SW Hway	343	<0.001	<0.001	<0.001	0.002	7	0.7	<0.02	<0.02	0.21	0.02	0.01
WB 2	Mar-00	Wungong Bk 0.5 km E of SW Hway	244	<0.001	<0.001	<0.001	<0.001	<5	0.3	<0.02	<0.02	0.16	0.01	0.02
WB 2B	Mar-00	Wungong Bk at Gull Street	331	<0.001	0.001	0.001	<0.001	<5	0.6	0.02	<0.02	0.2	0.01	<0.01
WB 3	Mar-00	Wungong Bk / Southern R at Forrest Rd	342	0.001	0.002	0.002	0.001	<5	2.2	0.02	<0.02	0.21	0.01	0.01
Southern River														
SR 2	Mar-00	Southern R @ Palomino Park	496	<0.001	0.002	0.002	0.015	13	8.1	0.16	0.22	0.96	0.14	0.14
SR 3	Mar-00	Southern R @ Bullfinch St	852	0.004	0.001	0.002	0.001	78	2	0.07	0.11	0.79	0.09	0.09
SR 4	Mar-00	Southern R @ Fremantle Rd Bridge	1090	0.002	0.001	0.002	<0.001	79	2.4	0.03	0.2	0.87	0.1	0.08

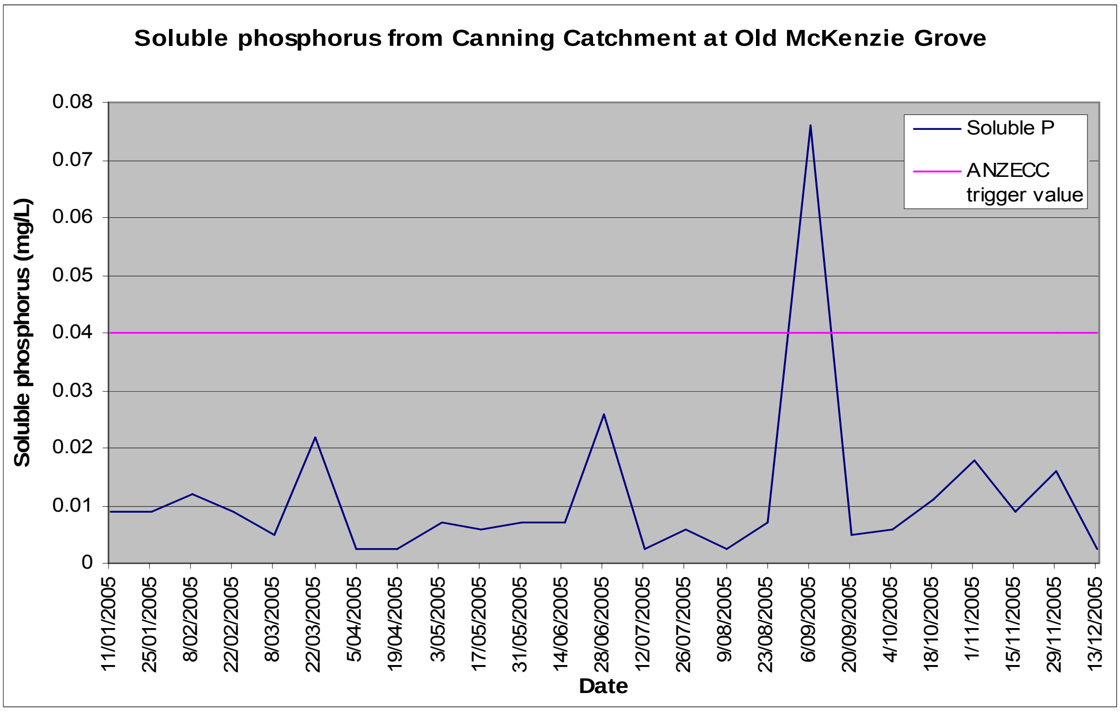

Figure 12: Soluble phosphorus from the Canning catchment measured at McKenzie Grove in 2005

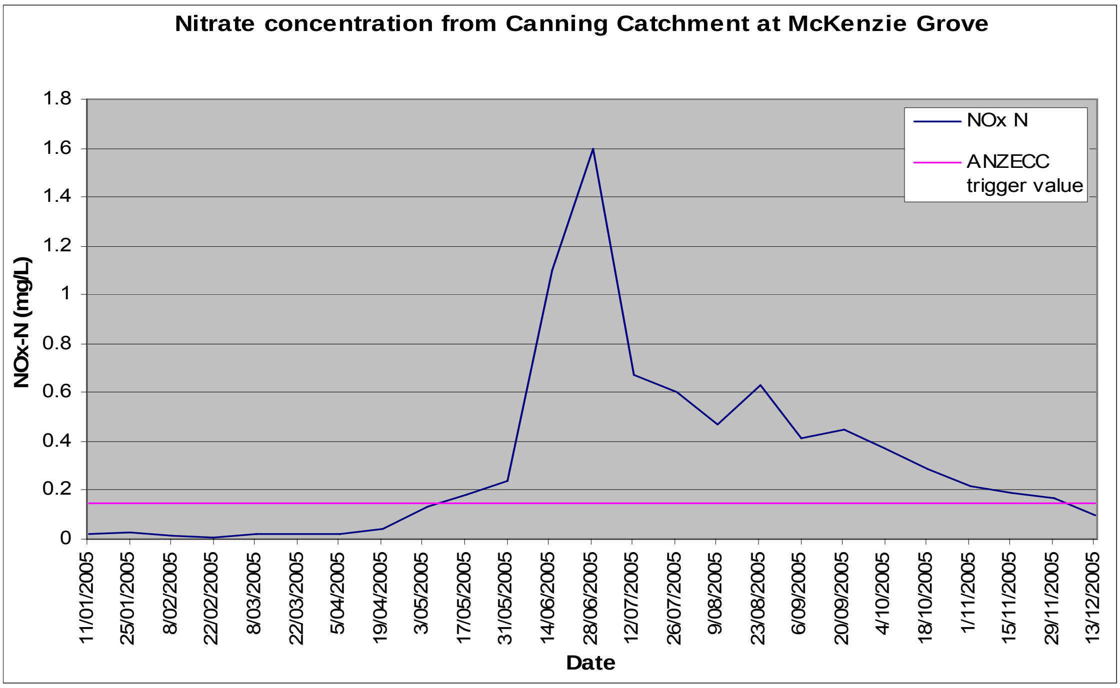

Figure 13: Nitrate concentration from the Canning catchment measured at McKenzie Grove in 2005

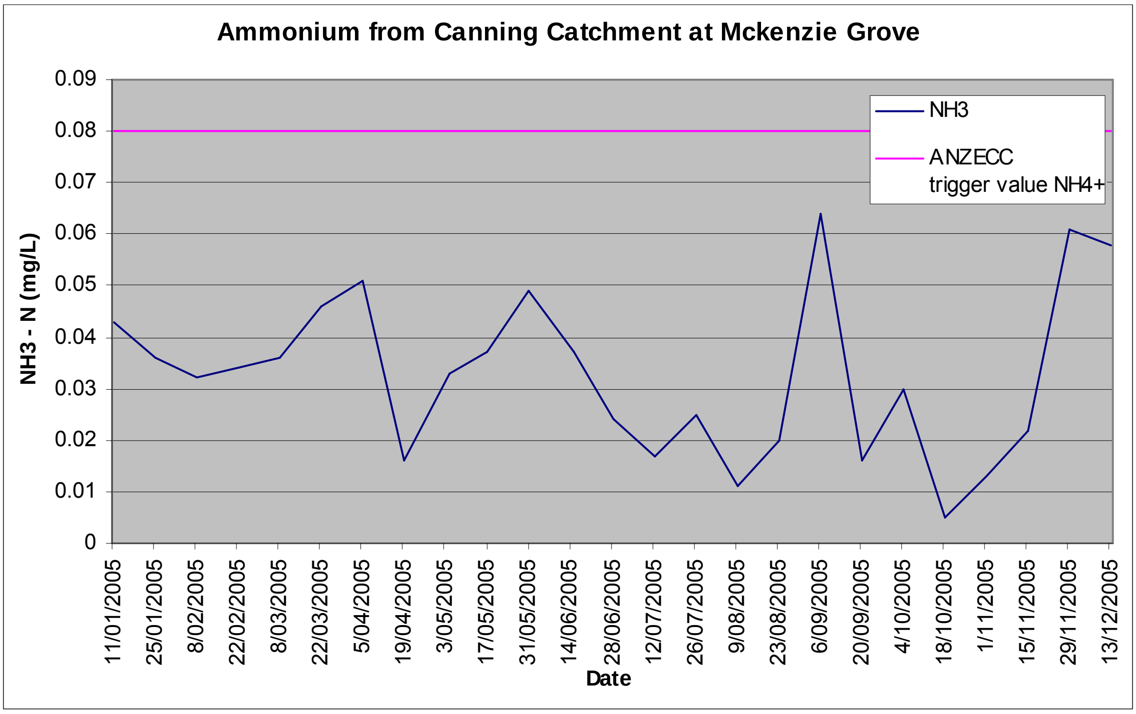

Figure 14 Ammonium concentration from the Canning catchment measured at McKenzie Grove in 2005

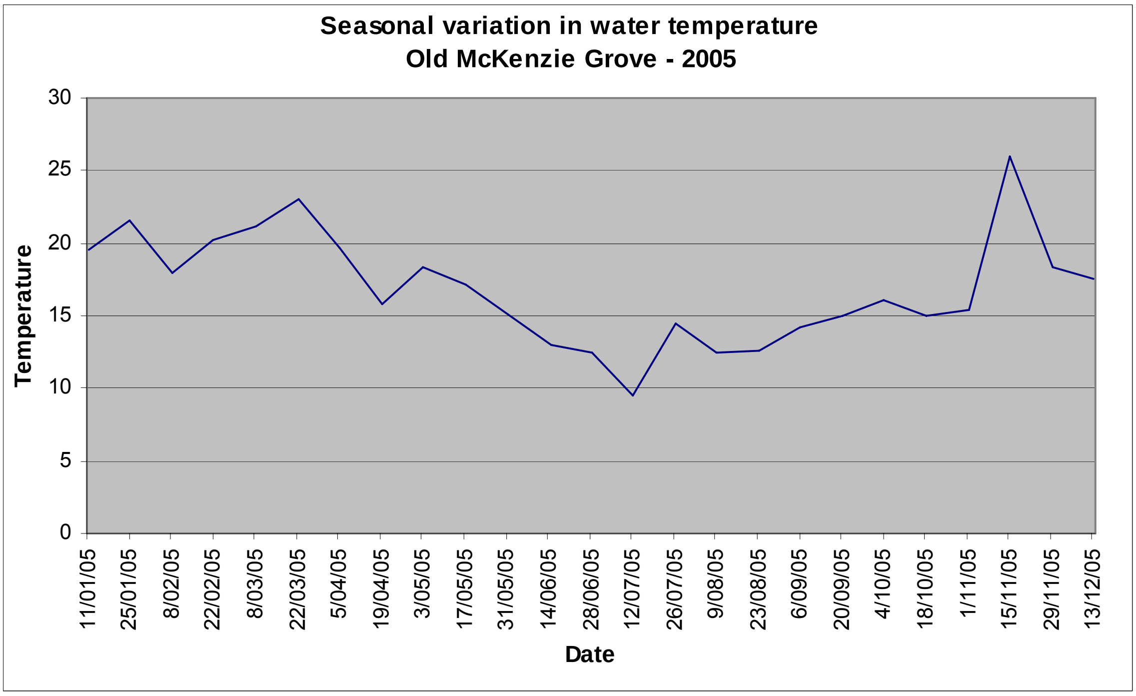

Figure 15 Seasonal variation in water temperature measured at McKenzie Grove in 2005