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Avon Catchment Council

Report for Surface Water Management and Self-Sufficiency

Environmental Water Flow Requirements

June 2009

INFRASTRUCTURE | MINING & INDUSTRY | DEFENCE | PROPERTY & BUILDINGS | ENVIRONMENT

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Executive Summary

This report forms part of an investigation undertaken for the Avon Catchment Council (ACC) within the Water Management and Self Sufficiency Project – IWM006. The report is part of a project focussed on assessing the impact of farm dams on environmental flows within the Avon River. The aim of the investigation was to provide a preliminary determination of the effect that increased catchment storages, namely in the form of farm dams, have on the environmental flows of the Avon River.

The report reviews available published information on environmental attributes of the Avon Arc catchment in order to identify the ecological values and key environmental assets. The review examined the current status of the environmental attributes and discussed potential impacts as a result of changes to environmental flows of the Avon River. The environmental attributes assessed included:

» *Hydrology;*

» *Geomorphology / Channel Dynamics and Sedimentation;*

» *Water Quality;*

» *River Pools;*

» *Aquatic and Riparian Vegetation;*

» *Fish Assemblages; and*

» *Macroinvertebrates.*

A preliminary assessment of the potential impact increased water harvesting may have on the Avon River and its ecological values was undertaken and preliminary environmental flow objectives have been identified based on nearby systems including the Canning and Blackwood Rivers.

One of the key environmental assets of the Avon River are the river pools, which act as important summer refuges for aquatic and terrestrial fauna, and have high ecological and social values. Many of the river pools are dependent on fresh water inputs from groundwater seeps and upwelling zones identified as local groundwater sources, together with the assurance of fresh late season river flows.

The long term sustainability of all environmental attributes identified herein can be maintained primarily through the maintenance of the flow objectives described in detail in Section 6. The majority of flow objectives are centred on maintaining the quality of late season river flows which can be achieved through the management of key catchments such as the Dale River catchment and through regulation of the construction and siting of catchment storages. Key flow objectives include:

» *Limitation of off-stream dam catchments;*

» *Protection of groundwater resources surrounding River Pools to ensure continued discharge of low salinity groundwater;*

» *Maintain significant flows to maintain the active channel morphology;*

» *Maintain sufficient late season fresh water flows in order to ensure that salinity of river pools does not*

increase above 8 000 mg/L TDS at cease-to-flow; and

» *Focusing investigations and management of high priority catchments such as the Dale River catchment.*

Further, the successful management of the Avon River and its environmental attributes requires a collective effort by responsible parties and landowners together and is dependent on this.

1. Introduction

GHD were contracted by the Avon Catchment Council to deliver the 2005 - 2008 Investment Project: Surface Water Management and Self-Sufficiency IWM006.

This project includes elements associated with improving self-sufficiency for water use within the Avon River Basin, and reducing reliance on the Water Corporation Water Supply Scheme (IWSS), the "Scheme". There are opportunities to reduce annual water benefits and improve the water balance of the region by increased water harvesting and reducing flooding and erosion. However it is imperative that adequate stream flow in the river is retained for environmental requirements.

This report contains a review of the methods currently available for assessing the ecological water requirements (EWR) of a river. The report also reviews available published information on environmental attributes of the Avon Arc catchment in order to identify the ecological values and key environmental assets. A preliminary assessment of the potential impact increased water harvesting may have on the Avon River and its ecological values is also undertaken and preliminary environmental flow objectives have been identified based on nearby systems including the Canning and Blackwood River.

Taking these into account, a proposed methodology for undertaking an EWR on the Avon River will be devised, which will be undertaken in Year Three of this project.

This report comprises the first of a series of three reports that investigate environmental flows, constructed storages and Local Government planning provisions regulating dam construction:

» *Preliminary Environmental Flow Analyses for the Avon River (GHD 2008a);*

» *Constructed Storage Analysis for the Avon River (GHD 2008b); and*

» *Recommended Planning Provisions – Construction of new Strategies within the Avon Arc (GHD 2008c*).

1.1 Relevant Management Action Target

The Management Action Target relevant to this project component is:

> **W3 MAT 5.3** Avon Arc Strategy and Local Government town planning schemes within the Avon River Basin include planning for provision of environmental water requirements by 2009.

1.2 Environmental Water Requirements

The flow of a river is fundamental to its ecosystem, providing habitat for many organisms and supporting a variety of critical ecological processes. The aquatic ecosystem can be threatened when significant alterations to the natural flow regime occur, through changes to the timing, duration and magnitude of flows. It has been recognised there is a need for a balance for how much water is taken out and how much is left to maintain the environment. Environmental water requirements are defined as the quality and quantity of water required by an aquatic ecosystem for the protection and maintenance of its

structure, functioning and dependent species (Smakhtin *et al*. 2003).

A framework for providing water to ecosystems has been developed by the ARMCANZ and ANZECC, forming the National Principles for the Provision of Water Ecosystems (ARMCANZ, 1996), which states that “the goal for providing water for the environment is to sustain and where necessary, restore ecological processes and biodiversity of water dependent ecosystems”.

This framework was taken into account when the *Statewide Policy No. 5*, *Environmental Water Provisions Policy for Western Australia* (Water and Rivers Commission, 2000) was written, which outlines the approach to be followed to determine how water will be provided to protect ecological values when allocating the rights to use water in Western Australia. The policy also lists the guiding principles to be followed when making such decisions and outlines a water allocation planning framework in which these principles are to be applied. This is the only current policy or legislation regarding environmental water requirements in Western Australia.

The National Water Initiative (NWI) is a strategy driven by the Australian Government to improve water management and explicitly states one of its main objectives is to have “more sophisticated, transparent and comprehensive water planning that deals with key issues such as the major interception of water, the interaction between surface and groundwater systems and the provision of water to meet specific environmental outcomes” (Department of Premier and Cabinet 2007). It is likely that the new water legislation that is currently being written will explicitly state the requirement for these to be undertaken in response to the NWI.

2. Environmental Flow Methodology

Many methods have been used to determine environmental water requirements both in Australia and overseas, however due to the variability associated with many of Australia's rivers (Finlayson and McMahon 1998), combined with the biological communities adapted to this variability, methods are not generally transferable to Australian conditions (Thoms and Swirepik 1998). In addition, other methods specific to Australian conditions have been developed and these are discussed below.

Australian rivers are unique on a world scale and geographic areas within Australia can be very distinct. Traditionally, environmental flow determination in Australia has focused on hydrology and habitat requirements for fish communities. Doeg (2000) suggests environmental flow determination falls in to three main categories

» *Hydrological methods;*

» *Habitat based methods; and*

» *Holistic methods.*

These three methods will be explored in greater detail below.

2.1 Hydrological Methods

Hydrological methods are defined using historical flow data to establish a percentage of mean annual flow or a specific hydrological index that achieves a particular objective.

They have advantages in terms of limited data and resourcing, however this approach relies on the assumption of a relationship between environmental protection and preserving a set percentile of flow. This theory is untested for Australian rivers and therefore is relatively indefensible. At best, this method can be used as a first pass assessment of likely environmental flow requirements from a resource planning perspective; however hydrological models should not be used in isolation from ecological studies of a system for the purpose of determining environmental flow requirements (SKM 2002).

2.2 Habitat based Methods

Habitat based methods are those that attempt to define the relationship between discharge and the amount and type of suitable fish habitat that is provided. Methods include the Instream Flow Incremental Method (IFIM) and the Rapid Habitat Assessment Method (which is a modified version of the IFIM that can be completed in a shorter time period and with fewer resources).

The advantage of the Rapid Habitat Assessment Method is that data can be collected from a specific river, with the use of an indicator species that is well known relative to other species. However, this method is based on the premise that by providing a certain amount of available habitat for the nominated native fish species, this will be adequate to protect the ecosystem in its entirety and this is yet to be rigorously tested in Australia.

2.3 Holistic Methods

Holistic Methods are those that assemble a panel of experts to integrate information from a range of disciplines including hydrology, ecology, water quality and geomorphology. Methods include the Building Blocks methodology, Holistic Approach, Decision Support Systems and Scientific or Expert Panel Approach. Recent assessments are based on a more holistic approach that considers the range of flow events in a typical flow regime (such as flush flooding and cease-to-flow) and the requirements of several ecosystem components (such as riparian vegetation, floodplain wetlands, geomorphic features and estuaries) (National Water Commission 2007).

The use of Scientific Panels has been successful in identifying likely environmental flow requirements of several regulated river systems in Australia. The Scientific Panel approach consists of a series of observations made on the geomorphological, hydrological and ecological character of a river, in a systematic and rigorous manner. These are combined with current and historical data to provide an assessment of river condition, hypotheses for the interactions between the river ecosystem and the flow regime and recommendations for environmental flow strategies. The key strengths of this method is that it is multi-disciplinary and is based on the best available data and expert opinion, which means the results have a high level of defensibility.

However the use of expert opinion in systems with virtually no existing ecological data, which is the case for many unregulated systems, is likely to have a limited effectiveness. Although the lack of ecological data is not limited to this method, it is consistent of many methods. The ability of the method to provide recommendations at the scale of private diversions in streams in low flow periods, where small change in discharge can have large consequences, is limited.

This method also relies on knowledge of the functional relationships between the hydrology and ecology of the river system. This knowledge may not exist or if it does, it is in historic reports or with local ecologists and turning this knowledge in to usable information requires skilled facilitators (Acreman and Dunbar 2004).

2.4 Current Approach used by Department of Water

Provision of water for the environment is considered within the water allocation process. The initial stage is to quantify the environmental water requirement (EWR), which is the water regime required to maintain ecological values of water dependent ecosystems at a low level of risk.. The EWR is then taken in to account with the social and economic values to ascertain the environmental water provision (EWP). The EWPs and the sustainable yield are the basis for the water allocation plans.

In Western Australia, the level of detail required for an environmental water assessment depends on the demand on the resource. Where consumptive pressures are low, hydrological approaches are still used. For example, in the south-west, such systems are estimated to have a sustainable yield of 60 per cent of historical mean annual flow, with 40 per cent allocated for environmental needs (National Water Commission 2007a). Where demands are higher, more detailed holistic approaches are used. In the past, the building block method has been applied to set limits on water provisions. The wet perimeter approach has also been used in Western Australia, particularly the Ord River in the Kimberly. However, the State Department of Water is now using the flow events method supported by River Analysis

Package software that allows the quantification of changes in ecological parameters with flow regime spatially and temporally. Analyses were completed for 22 flow ecology linkages using three representative reaches of the lower Ord. Where appropriate, individual flow recommendations were developed for each reach for each flow ecology linkage. The flow recommendations for individual flow ecology linkages were consolidated and summarised into a dry season and wet season EWR. Dry season flow recommendations are typically presented as minima below which flows should not fall.

3. Environmental Flow Methodology for the Avon River

The Avon River is one of south western Australia's major rivers, with a greater catchment area exceeding 120,000 km^2. The Avon River is approximately 270 km in length and extends from the source of its main channel in the Shire of Wickepin to the confluence with Wooroloo Brook at Walyunga National Park where it becomes known as the Swan River (Harris 1996).

Significant changes have occurred to the Avon River hydrological regime and channel morphology since European settlement, resulting from widespread clearing of the catchment for agriculture and the River Training Scheme (RTS). These two primary disturbances have largely determined the contemporary river response and flow-ecology linkages of the Avon River.

Stream flow in the Avon River is determined by seasonal rainfall, evaporation patterns and weather events. As a general rule, flow in the main channel of the Avon River commences in the autumn and continues through to mid-summer. During the hot and dry summer months of December to February, the Avon River dries into a series of deep pools. Given this, one of the primary objectives of the environmental flow assessment will be to maintain water levels and water quality in these deep pools. The range of flow events that are typical of the Avon River flow regime (such as flush flooding and cease-to-flow) and the requirements of several ecosystem components (such as riparian vegetation, floodplain wetlands, geomorphic features) will also be considered.

The key flow related issue that will be considered within this preliminary assessment is the potential impact that an increase in catchments storages, in this case farm dams, may have on the flow-ecology linkages within the Avon. A more detailed quantitative assessment of the hydrological effect dams have on environmental flows is explored in a subsequent report (GHD 2008b).

It is recognised that catchment storages (farm dams) provide an important source of water that can help to reduce farming risks during periods of low rainfall (Schreider *et al.* 2002). However, there are environmental risks associated with the lack of regulation of surface water allocation within the Avon River Basin, and the potential future increases in either dam size or dam density within areas of the catchment (GHD 2009).

3.1 Study Objectives

The objective of this project is to identify the ecological values and key environmental assets for the Avon River within the Avon Arc catchment (Figure 1). There is concern that an increase in catchment storages, in this case farm dams, or changes to land management through commercial and residential development may negatively impact the flow-ecology linkages of the river, further disconnecting the river from its floodplain, while resulting in further degradation of late season water quality in the river pools.

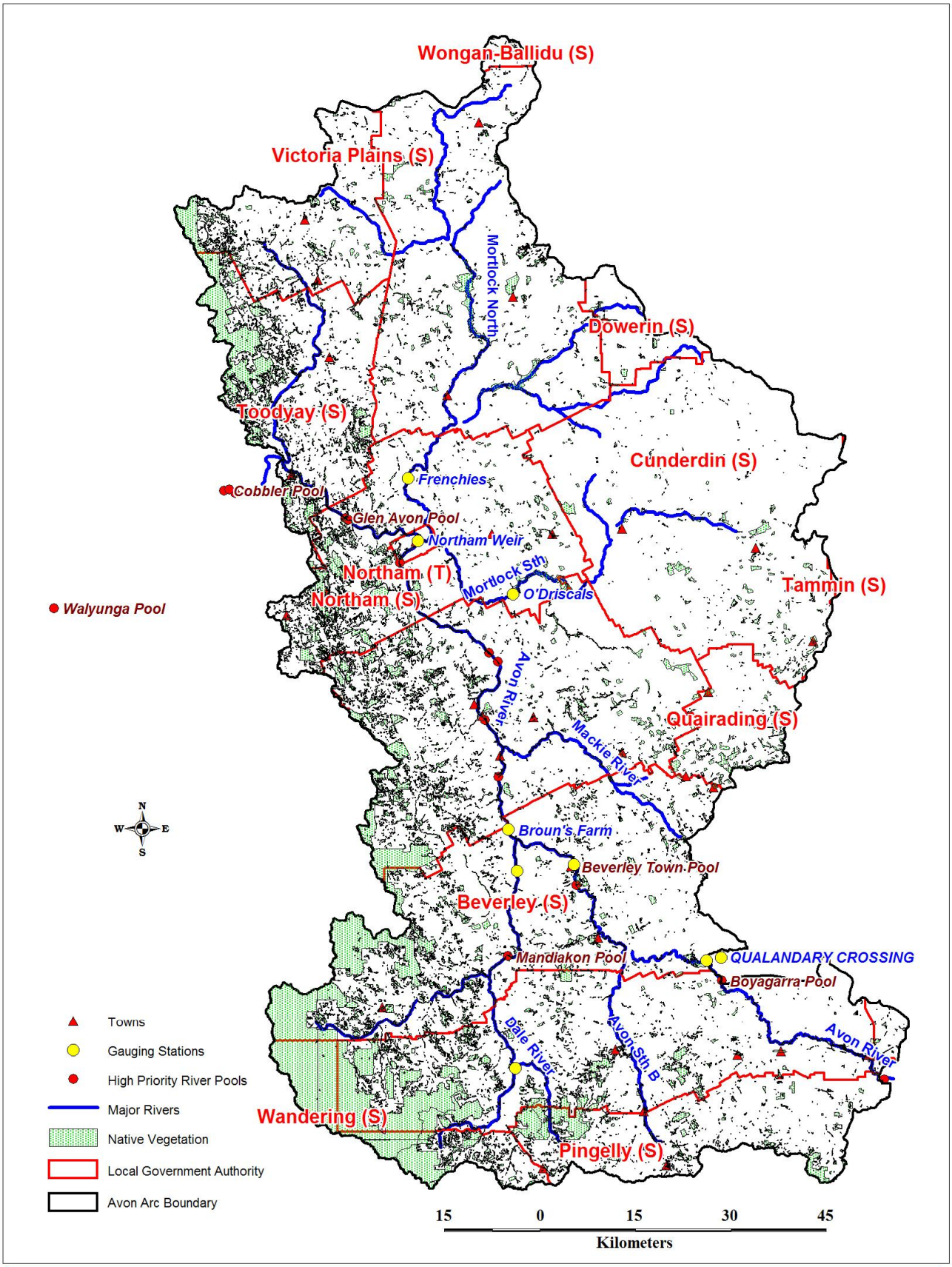
The preliminary flow objectives, based on environmental water requirement studies within other south-west rivers including the Canning River and Blackwood River, provide an overview of flow requirements for identified ecological values of nearby systems.

Specifically the objectives are:

- *Collation of existing information;*
- *Identification of information gaps;*
- *Identification of flow dependent ecological values of the Avon Arc catchment;*
- *Preliminary assessment of the risk to flow dependent ecological values associated with changes to water regimes; and*
- *Make recommendations for environmental flow requirements throughout the Avon Arc catchment based on available information.*

In the following sections several key environmental attributes of the Avon River are discussed in detail to identify their current status and how they are affected by environmental flows of the Avon River including water quality, water quantity and changes to the river dynamics. The environmental attributes identified and discussed are:

- *Hydrology;*
- *Geomorphology / Channel Dynamics and Sedimentation;*
- *Water Quality;*
- *River Pools;*
- *Aquatic and Riparian Vegetation;*
- *Fish Assemblages; and*
- *Macroinvertebrates.*



Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone 50

Figure 1. Avon Arc catchment

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4. Environmental Attributes

4.1 Hydrology

4.1.1 Annual streamflow

The Avon River, like many river systems in the south-west of Australia, is characterised by high flow variability. Stream flow within the Avon River is intermittent in response to the Mediterranean climate of the region and is largely responsive to winter rainfall. The river usually commences flow in April after the onset of winter rains, reduced temperatures and evaporation. The main tributaries of the Avon River include the Mortlock North, Mortlock South, Dale River and Mackie River. The headwaters of the Avon River are considered to be the tributaries of Lake Yealering (DoW 2006a), the large salt lake within the Zone of Ancient Drainage, however this part of the catchment only contributes to flows periodically when rainfall is high in the eastern catchment (JDA 1997).

During the summer months the area of the catchment that contributes to river flow tends to shrink from the headwaters in response to reduced rainfall and increasing evaporation. Flow generally diminishes or ceases before Christmas and the river dries up into a series of isolated pools. Permanent pools exist over summer along the main Avon River branch and within the Mackie River.

The streamflow regime of the Avon River is typical of a seasonal river. The flow regime is characterised by periodic high flow events of varying magnitude and duration (occurring in response to rainfall events), superimposed on baseflows that are derived primarily from soil water and ground water. The key characteristics of the flow regime are the number, magnitude, frequency and duration of high flow events, the timing and range of low flows and the inter-annual variability of these flows. The primary phases throughout the annual cycle (after Government of South Australia 2007) include:

a. Flush and flooding flow phase – medium to high flows, including up to bank full flows and those that inundate floodplains (moves sediment and vegetation; restores habitat, breeding, germination and growth of river plants).

b. Wet connected phase – pools are connected by flows to allow flora and fauna to move and recolonise the river from refuge pools (different species require different flow rates).

c. Wet isolated phase – pools contain water but flows do not link pools (provides important wet refuge sites for flora and fauna).

The amount of time the Avon River spends in each of these hydrological phases (i.e. Wet Isolated phase, Wet Connected phase, Flush and Flooding phase) is largely dependent on its location within the Avon Arc Catchment. The downstream catchment areas spend a larger period of time in the Wet Connected phase due to the larger catchment area contributing to discharge at these points. Other influences that may impact the timing of the phases include climatic factors (i.e. wet year versus dry year and evapotranspiration) and non-climatic factors (such as catchment storages).

The hydrological balance of the Avon River catchment has been significantly disturbed by two activities within the last century:

- *Broad scale clearing for agriculture; and*
- *River Training Scheme (RTS) (Harris 1996).*

These activities are estimated to have increased the annual flow rate of the Avon River by a factor of 3 or 4 (WRC 2002). The RTS channelised the Avon River and was designed to mitigate flooding by increasing flow velocities.

4.1.2 Annual and seasonal variability

The annual and seasonal streamflow in the Avon River and its tributaries varies between wet and dry years. Rainfall within the catchment can exhibit large inter-year variability with occasions where rainfall has varied by a factor of two between years (Harris 1996). Large discrepancies in stream flow contributions throughout the catchment may also be attributed to the variability in rainfall distribution, with mean rainfall diminishing between the western and eastern parts of the catchment. Further due to the large size of the catchment rainfall does not fall uniformly. The flow regime is also dependent on rainfall timing and intensity.

During wet years the river above 'Brouns Farm' gauging station near York can contribute over 40% of total streamflow, while in a dry year the contribution may only be 12% (Harris 1996). Similarly the Mortlock River may contribute up to 14% of annual streamflow (as measured at Walyunga) during wet years, though may contribute as little as 3% in dry years (Harris 1996). Yates Heritage Consultants (1999) reported that "few recorded incidences of drought in the first half of this century noted no flow at all (Walker 1986)". Masters (1992) reports because of winter droughts in 1914 and 1940 the Avon didn't flow at all.

Table 1 displays the seasonality and high variability of streamflow within the river at the Northam Weir gauging station for 30 years (1977-2006).

Table 1 Annual and season flows in Avon River at Northam Weir (615062) gauging station between 1977-2006

Statistic	Water Year Apr-Mar GL	Wet Season Apr-Oct GL	Dry Season Nov-Mar GL	Dry Season m^3/sec
Mean	104811075	92860714	12362442	0.95
Historic maximum	424339092	314838470	224566893	172.0
90th percentile	227653890	201234857	12553790	0.3
75th percentile	134958889	112410619	3563585	0.0
50th percentile	78918421	78792300	592289	0.0
25th percentile	37247875	33846554	166206	0.0
10th percentile	19705441	19700245	61394	0.0
5th percentile	15560889	15408999	29669	0.0
Historic minimum	10288572	9170921	10	0.0

Based on data of the Public Works Department, Harris (1996) examined the number of days of continuous flow in the Avon for the period 1979 to 1993 (Table 2). Using estimates for periods where no data was available Harris (1996) reported the Upper Avon persists for approximately 286 days, while the lower Avon at Walyunga persists for a longer period of approximately 310 days in the river year. The longer flow period of the Lower Avon was attributed to the higher rainfall zone of the tributaries within this region.

Table 2 Number of days of continuous flow in the Avon (From Harris 1996).

Year	Middle Avon Brouns Farm	Year	Lower Avon Walyunga[1]
1980	232	1980-81	271
1981	287	1981-83	652
1982-83	348		
1983-84	292	1983-84	331
1984-85	321	1984-85	325’
1985	290	1985-86	344
1986	310	1986-87	330
1987-88	276	1987-88	283
1987-88	99	1988-89	285
1988	262	1989-90	279
1989	248	1990-91	346’
1990	325	1991-93	640+’
1991	236		
1993	258		

[2] – Indicates values were estimated

4.1.3 Flood responses

The flood response of the river is largely dependent on the aerial extent of rainfall within the catchment.

Major flooding within the Avon River has occurred in the years 1910, 1917, 1926, 1930, 1945, 1955, 1958, 1963 and 1983. Prior to the RTS the natural flooding regime of the Avon River was on a nine to eleven year cycle (Viney and Sivapalan 1999). Local observations suggest there has been limited flooding since the completion of the RTS, however the success of the scheme is unresolved as no floods of more than 1:50 year magnitude have occurred during this period (WRC 2002).

4.1.4 Flow connectivity

A number of pools maintain permanent water over the summer months when the Avon River ceases to

flow (Isolated Pool phase). These pools represent important summer refuges for the aquatic and terrestrial fauna of the Avon and the long term sustainability of these habitats is an important consideration for future water management planning within the Avon Arc catchment.

In some years the summer Avon will flow in response to sporadic rainfall events, however the extent of flows may be uneven due to the localised impact of some summer storms (Harris 1996). An examination of the threshold response of summer storms concluded a single summer storm of at least 20 mm is required to initiate river flow, however the river response was dependent on antecedent catchment conditions (Harris 1996).

4.1.5 Hydrogeology

There is limited data regarding groundwater flows within the Avon region. Groundwater flow is generally from recharge areas along drainage divides (Viney and Sivapalan 1999). Of the various hydrogeological units within the catchment the Avon valley unit is not known to have extensive groundwater sources (Davies *et al* 1996), while the Darkin valley unit, in the western Avon catchment and the Mortlock valley unit have groundwater present in pallid zone aquifers. Davies (*et al* 1996) reports the pallid zone aquifers within the upper sections of valleys of the Darkin unit permanently feed tributary streams, while those of the Mortlock valley unit frequently maintain saline pools.

An assessment of groundwater resources of the Beverly and Brookton shires by Water Direct Ltd (2002) identified five basic aquifer types:

» *Fractured rock aquifers which yield fresh to saline water depending on the location in the landscape;*

» *Superficial alluvial aquifers which contain stock-quality water in small sand lenses between clay layers in drainage lines;*

» *Fresh to brackish springs flowing from sand mounds;*

» *A paleochannel aquifer, formed from an ancient drainage line, which yields fresh to brackish water; and*

» *A paleobasin which yields fresh to marginal water.*

There is further anecdotal information indicating that deep groundwater discharges into a number of river pools throughout the Avon Arc catchment year round. The groundwater discharges as either seeps or upwelling zones and inject fresh and/or saline water plumes, depending on surrounding groundwater quality, into the generally brackish waters (Lewis 2008). Further, ground and surface waters are likely to be present within weak bedrock zones, many of which are likely to be linear. Characteristics of bedrock throughout the Avon region were interpreted as highly irregular and rapidly changing over short distances, leading to the assumption that groundwater systems are compartmentalised and controlled by local geological structures (Lewis 2008).

Therefore the groundwater systems present within the Avon region are complex and governed largely by the interactions between river water levels, groundwater levels and connectivity.

4.1.6 Flow related issues

The impact of increasing farm dams on river flows is cumulative, and is greatest on low to mid flows and in below average rainfall years. The cumulative volume held by numerous off-stream farm dams may delay the on-set of flows by effectively reducing the groundwater contribution to these flows, due to capture storage within the dams. The cumulative impact of catchment storages is likely to increase the duration of the Wet Isolated phase, while reducing the magnitude of the Flush and Flooding phase.

The timing and magnitude of low to mid flows (Wet Connected phase) may be also impacted by an increase in catchment storages as these require the wetting up of the catchment prior to their onset.

An increase in the number and the storage capacity of farm dams will lead to reduced catchment runoff due to the greater capacity to store larger volumes of water.

4.2 Geomorphology/Channel Dynamics and Sedimentation

The main Avon River channel flows through the Zone of Rejuvenated Drainage and is defined by the Meckering Line to the east and the Darling Range to the west (DoE 2006). The western part of the catchment is characterised by greater dissection and steeper gradients than the Zone of Ancient Drainage to the east (DoE 2006). The section of the river between Beverly and Toodyay has a relatively low gradient of 0.8 m/km, increasing to 1.6 m/km downstream of Toodyay where the river descends to the Swan Coastal Plain (Harris 1996).

Two primary catchment disturbances have shaped the existing Avon River geomorphology. The first disturbance was the widespread clearing of the catchment which commenced in the 1840's, increasing during the early 1900's, resulted in a changed catchment water balance and mobilisation of the historical salt store. The rising ground water table intercepted the soil salt store and resulted in secondary, or human induced, salinisation of the landscape including the streams draining it. Clearing of deep rooted woodland vegetation and agricultural practices such as grazing have also mobilised hillslope sediment, contributing to increased soil erosion, while degradation of riparian vegetation has resulted in bank erosion in some parts of the catchment.

The second disturbance was the RTS, which resulted in a dramatic and immediate change to the stream morphology. The RTS was undertaken between 1958 and 1972 for almost the entire channel length from below Toodyay to the upstream extent of Aldersyde (Water and River Commission 2002). This involved:

» *Removal of channel vegetation and debris to a width of 60 metres;*

» *Removal of dead trees, logs and debris which impaired the river flow;*

» *Ripping of the river bed to induce erosion of a deeper watercourse; and*

» *Removal of minor kinks and bends in the river.*

Prior to the RTS the characteristic features of the Avon River channel in the Zone of Rejuvenated Drainage included a primary braided channel featuring vegetated islands, anabranches, pools and riffles. The RTS dramatically changed the morphology of the river channel. The ripping of the riverbed resulted in mobilisation of significant volumes of sediments, greatly increasing the size of the sediment load within the river. One of the more visible impacts on channel morphology is scouring of the channel in some

sections and infilling of downstream river pools with the scoured sediment.

The scheme increased the depth and decreased the width of the Avon River, which opposes the natural processes that would occur under increased discharge conditions as a result of catchment clearing (Callow 1999). The RTS also created preferential channel flow, with the formerly braided river channels only functioning as alternative floodways (anabranches) during high flow events (DoW 2006b).

The lowering of flood levels by the RTS has disconnected the Avon River from over half of its original floodplain (Hansen 1986). As a result sediment that would normally be deposited within the floodplain is carried by in-channel flows. Sediments have now become the driving force behind morphological change within the river. In some sections of the river channel the river is reaching a new equilibrium with reformation of bars and channel braiding, along with regeneration of vegetation. A study of the Boyagarra Pool section of the Avon River found that substantial aggregation of sediments and formation of lateral bars was slowly forming a braided stream channel (Viney and Sivapalan, 1999).

Sedimentation of the river pools appears to have stabilised in recent years, indicating the available bed load is declining, however the process is likely to continue to an extent due to bank and catchment erosion processes (WRC and ARMA 1999).

4.2.1 Sediment Dynamics

Prior to the RTS the sediment dynamics of the Avon River were predominantly driven by the occurrence of large floods, with the suspended sediment load likely to have been dominated by silt-sized sediments. The higher flow rates that were achieved following the RTS and the destabilisation of in-stream channel features is likely to have resulted in a higher bed load of sediment transported by the river, which is the source of sediment within the infilled pools (Southwell 1993). The sediments within Northam Pool and Burlong Pool are medium to coarse sands (Pearce, 1987; Southwell, 1990), indicating transport by medium to high energy conditions.

While the RTS is considered to be a major source of the high sediment load within the Avon River, geomorphological processes including bed scour (Southwell 1990), bank erosion and broad scale catchment erosive processes are also considered key contributing sources. The decline in soil structure due to secondary salinisation has further contributed to catchment erosion (Olsen and Skitmore 1991).

There is evidence in some river sections the river morphology is returning to its previous braided form, with stabilisation of channel sediment in the form of bars and islands, occurring in response to regeneration of in-stream vegetation. Modelling of channel flow characteristics by Southwell (1993) found stabilisation of the channel sediment through re-establishment of channel vegetation was of primary importance in preventing further infill of river pools.

4.2.2 Flow Related Issues

Clearing of the catchment has resulted in flow responses to rainfall becoming more rapid, resulting in widespread catchment erosion, scouring of the river bed and general degradation of the river. Within a number of reaches scour of the river bed has incised the channel to bedrock. The sediment mobilised through erosion and scouring is deposited downstream as sediment slugs within river reaches and river

pools, resulting in a number of the river pools having filled or become substantially infilled in response.

In order to be geomorphologically effective (i.e. to mobilise sediment stored in river pools or initiate planform modification) flows need to be of a sufficient magnitude and duration so as to generate enough stream power to cross intrinsic thresholds that limit change. The Avon River has not received a flood of sufficient magnitude to rework the river channel and scour river pools in the period since the RTS (Callow 1999).

Anecdotal evidence presented by Harris (1996) indicates that pre RTS a number of the pools were of the order of 7 m deep. Pearce (1987; in Harris 1996) undertook theoretical and physical model studies that indicated flows of 300 $m^3 s^{-1}$ would be required to scour down to a maximum depth of 4.6 m, while 100 $m^3 s^{-1}$ would be required to scour to 1.2 m. Flows of this magnitude are rare within the Middle Avon where the majority of pools occur. An alternate modelling study by Southwell (1993) suggested events with a return period exceeding 30 years were of sufficient magnitude to scour river pools. Southwell (1993) determined flood events in 1983 (372 $m^3 s^{-1}$ observed) and 1963 (692 $m^3 s^{-1}$ modelled for Northam to Toodyay reach) were in the range of 10 and 20 year return events respectively and much of the sediment transported by these events would have contributed to pool infilling.

Therefore the increased flow rates achieved by the RTS were sufficient to transport large quantities of bed scoured sediment into the pools, however the lack of significant flood events post RTS resulted in a rate of accretion that exceeded the rate of erosion by pool-scouring processes (Harris 1996).

Attempts to restore the natural channel characteristics of the Avon River are likely to be hindered by gaps in the knowledge regarding the fluvial mechanics, geomorphological controls on channel characteristics, sediment transport and sediment yield data (Southwell 1993).

4.3 Water Quality

Prior to clearing the Avon River and its tributaries were predominantly fresh. Periods of saline flows occurred when the extensive salt lakes in the upper catchment contributed to stream flow.

Since clearing the Avon River has become increasingly saline. The development of secondary salinity in response to rising water tables and mobilisation of the sediment salt store is the most significant water quality issue within the region. Anecdotal evidence also indicates that following European settlement and wide scale clearing of the catchment for agriculture, there has been frequent occurrence of other water quality issues including algal blooms within the river pools during the summer months.

Water quality monitoring of the Avon River has been undertaken in a temporarily and spatially ad-hoc manner by various interest groups including government agencies, research groups and community groups.

Future threats to the ecological attributes of the Avon River include deep drainage of groundwater to prevent water-logging and reduce the impact of salinity on farming land. The major threat presented by drainage discharge is the low pH (very acidic). Very low pH (less than 4) or large fluctuations in pH will negatively impact upon aquatic biota of the Avon.

4.3.1 Nutrients

The Avon Catchment Council (ACC) has set the following targets for the Avon River:

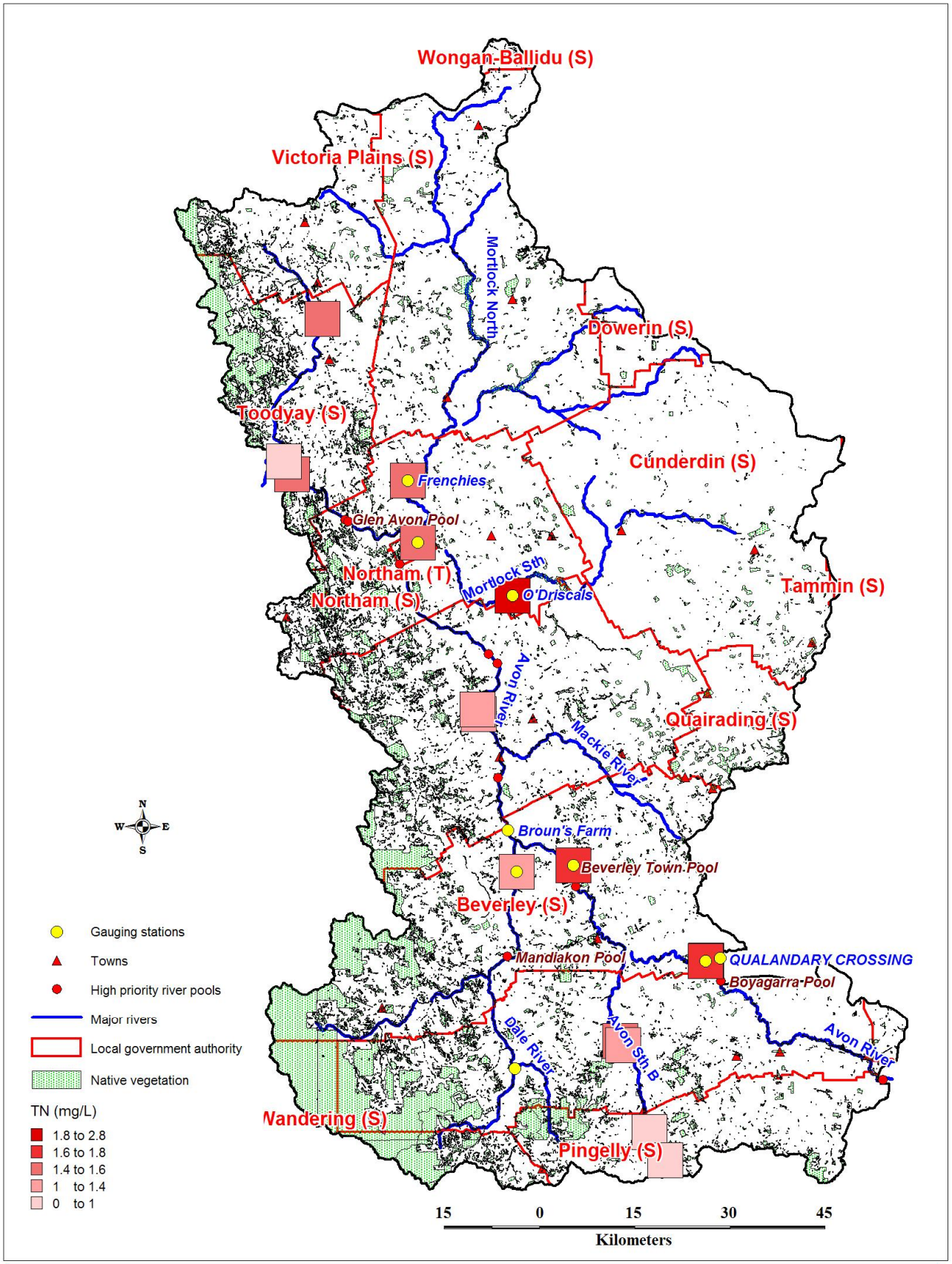
» *Total Nitrogen (TN) - average monthly concentration should not exceed 1 mg L^{-1}; and*

» *Total Phosphorus (TP) - average monthly concentration should not exceed 0.1 mg L^{-1}.*

These levels have been found to be exceeded during large summer rainfall events and often contribute to algal blooms within the Avon River itself and the Swan River Estuary downstream (DoW 2007b).

Summer flow events can have serious impacts on the summer pool refuges due to the mobilisation of significant quantities of nutrients that have built up from organic matter breakdown and livestock grazing during the summer period (Harris 1996). In addition to algal blooms high nutrient loads to the river pools during the summer months has resulted in the development of anoxic conditions and subsequently led to aquatic fauna deaths.

The distribution of mean TN and TP concentrations measured within the Avon River and its tributaries are presented in Figure 2 and Figure 3. These figures highlight the high nutrient concentration contributions from the Mortlock North and Mortlock South rivers and the relatively low nutrient concentrations within the Dale River.



Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone 50

Figure 2. Avon Arc TN distribution

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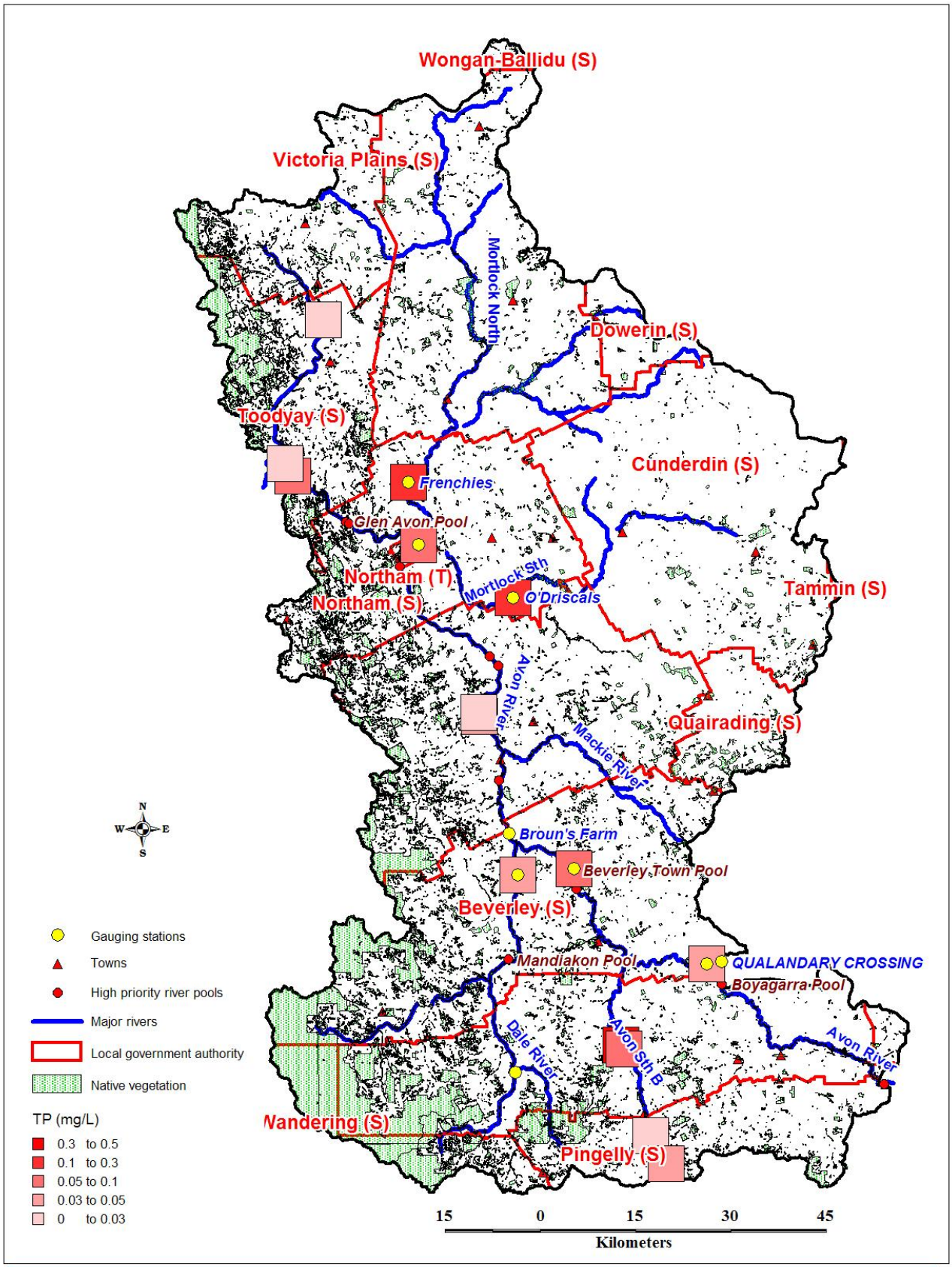

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone 50

Figure 3. Avon Arc TP distribution

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4.3.2 Salinity

Primary or natural salinity occurs within the eastern part of the catchment in the Zone of Ancient Drainage. This area comprises very broad, flat river valleys and extensive chains of salt lakes that are naturally brackish or saline and are internally or irregularly drained (Pen 1999). The salt lakes include Lake Yearlering, Nonalling Lake, White Water Lake and Brown Lake. Salinity within Lake Yealering was recorded at 267 000 mg L^{-1} TSS (i.e. more than seven times sea water salinity) in January 1981, while average September salinity is 32 700 mg L^{-1} (DoW 2006a). The watercourses within this region only flow in periods of exceptionally intense and widespread rainfall (Pen 1999).

Sporadic flow from the Zone of Ancient Drainage was the primary source of saline flows to the Avon prior to clearing of the catchment and the development of secondary salinity.

The impact that clearing deep rooted native vegetation had in raising stream salinity inland of the Darling Plateau was recognised by the 1920s (Schofield *et al.* 1988). The salt found within the soil profile within the Avon catchment has a similar ionic composition to sea salts (Sharma *et al*. 1980) and it is generally accepted that the salt is derived from the prevailing westerly winds picking up salt spray from breaking waves and transporting it inland.

Table 3 displays the average salinity and salinity status of key sites of the Avon River. The general trend in salinity status indicates that smaller sub catchments that have undergone less clearing and occur in higher rainfall zones contribute fresher water flows. In contrast sub catchments that occur east of the 400 mm rainfall isohyet and have undergone extensive clearing contribute disproportionately high salt loads to streamflow (DoE 2005a).

The most downstream gauging station of the Avon, at Walyunga, recorded an average salt load of 1.5 million tonnes for the period 1993 - 2002 (DoE 2005a).

Table 3 Average salinity of key sites on the Avon River (DoE 2005a)

Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km^2)	Salinity status	1993-2002 Mean salinity (mg/L TDS)
Lockhart River	90	350	6 050	Highly saline	33 900
Mortlock River North	96	380	2 333	Highly saline	15 000
Avon River Brouns Farm	86	380	26 856	Saline	6 600
Yilgarn River	82	310	11540	Highly saline	22 500
Mortlock River South	97	360	5 040	Highly saline	11 100
Avon River Northam Weir	86	390	28 485	Saline	6 700

Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km^2)	Salinity status	1993-2002 Mean salinity (mg/L TDS)
Dale River South	64	530	286	Moderately saline	3 700
Avon River Walyunga	85	400	40 401	Moderately saline	4 900

4.3.3 Freshwater Flows

An important process when considering the impact of flow on the ecology of river pools is the occurrence of fresh water inflows throughout the catchment. Sub-catchments that occur within the higher rainfall western portion of the Avon catchment generally contribute fresher flows than those within the lower rainfall, predominantly cleared, eastern part of the catchment (Section 4.3.2).

The Dale River has been identified as an important source of relatively freshwater inflow to the Avon. This is attributed to a number of features of the sub-catchment including its location within the western, higher rainfall zone, its comparatively low clearing level and the occurrence of numerous aquifers and springs that yield predominantly fresh to brackish water to the Dale. The aquifers and springs within the Dale sub-catchment include fractured rock aquifers, sand lenses, sand mounds, paleochannels and paleobasins (DoE 2006). Further Maitland Swamp has been identified as a relatively fresh tributary of the Dale River (Harris 1996).

Freshwater seeps and upwelling zones of deeper aquifers are also an important source of freshwater flows to the Avon River. These sites contribute fresh flows to river pools or river reaches, providing an important freshwater input, and are often hotspots for biodiversity. The location of freshwater seeps and upwelling zones have been recorded for a number of the reaches that were included in the River Recovery Plan series for the Avon catchment. However, there are likely numerous additional sites that have not been formally assessed and mapped.

The freshwater resources of the Avon Arc catchment should be considered priority river assets and measures should be undertaken to protect and maintain them.

4.3.4 Dissolved oxygen levels

The dissolved oxygen level within river pools plays an important role in the maintenance of habitat for aquatic fauna. During the Wet Isolated phase pools that have reduced volumes as a result of sedimentation may be unable to sustain adequate dissolved oxygen levels due to oxygen demand by plants and animals. Further, pools that do not receive freshwater inflows from groundwater inflows or hillslope seeps may also be impacted by anoxic conditions.

4.3.5 Flow Related Issues

Any reduction in flow volume to the Avon River and its tributaries is likely to alter the concentrations of

nutrients and salinity. The impact on identified ecological attributes is likely to be greatest if flow is reduced in the tributaries that have high water quality, resulting in a concentration of nutrients or saline water.

The water quality at cease-to-flow will assist in determining the suitability of the pool as a summer refuge for certain species, particularly more sensitive species such as those in juvenile stages or species that are intolerant of high salinities. The water quality at cease to flow may also predetermine the likely occurrence of algal blooms and anoxic events. Reduced late season flows will concentrate nutrients and salts and present a high risk to the ecology of river pools for the duration of the Wet Isolated phase.

As some tributary sub-catchments contribute water of a better quality than others it is preferential to maintain the quantity and quality of these sub-catchments, particularly prior to cease-to-flow of the river. It is important therefore that prior to any increase in catchment storages within tributaries identified as contributing water of a higher quality, consideration be given to the effect of poor late season water quality on the pools of the summer Avon River.

4.4 River Pools

The river pools of the Avon River have been identified as priority assets due to their ecological, social and economic values (DoW 2007c). Forming some of the rivers most valuable habitats, the river pools provide the only permanent summer refuge in an otherwise dry landscape (DoW 2007c). A number of the river pools hold important cultural and social value to the local residents of the Avon Arc catchment. Existing information regarding a number of the pools of the Avon River comes from local knowledge, as well as a number of channel and pool surveys that have been conducted pre and post RTS.

While the river pools and their dependent ecosystems have adapted to a fluctuating environment in terms of interannual variations in rainfall and river flows, a number of other factors including increasing salinity, sedimentation, nutrient enrichment and a changing flow regime still threaten these ecosystems (WRC and AWC 2002).

Pools that were identified as having high ecological value by DoW (2007a) are shown in Table 4. The pools were considered to be ecologically significant if they met one of the following criteria:

» *Significant depth to retain water and provide habitat during the summer months;*

» *Foreshore vegetation capable of sustaining a variety of terrestrial fauna; and*

» *The pool is located adjacent to a Reserve.*

Table 4 Ecologically significant rivers pools of the Avon River (DoW 2007a)

River Pool	RRP Section Name	RRP Section Number	Ave TP mg L^{-1}	Ave salinity (TDS) mg L^{-1}	Max water depth (JDA 1997)
Walyunga	Lower Avon	NA	ND	ND	
Cobblers	Avon Gorge and Deepdale Valley	1, 2	0.208	ND	2.50

River Pool	RRP Section Name	RRP Section Number	Ave TP mg L^{-1}	Ave salinity (TDS) mg L^{-1}	Max water depth (JDA 1997)
Long			0.028	7 891	3.19
Red Banks	Northam to Toodyay	4, 5	0.017	7 003	
Glen Avon			0.605	14 373	3.76
Katrine			0.129	18 157	1.96
Lloyds			0.021	7 568	4.41
Northam	Northam	6	0.129	20 787	1.20
Tipperary	Mile Pool to Spencers Brook	7, 8, 9	0.176	25 520	1.32
Mears			0.133	21 442	1.25
Wilberforce			0.056	12 100	4.35
Mile			ND	ND	
Mackie/Church			0.135	16 500	2.40
Railway	York	10	ND	ND	
Blands			0.081	15 081	
Gwambygine	Gwambygine to Edwards Crossing	11, 12	0.237	9 482	3.75
Fleays /Oakover			0.056	4 048	0.65
Beverly Town	Beverley Townsite to Edwards Crossing	13	0.081	30 748	3.58
Eyres	Beverley to Qualandry Crossing	14,15, 16	ND	ND	
Kokeby			ND	ND	
Jurakine			ND	ND	
Green			ND	ND	
Boyagarra	Aldersyde to Kweda	19	0.044	15 807	
Dwarlacking		19	ND	ND	
Quandadine		19	ND	ND	
Jangerin		19	ND	ND	
Waterhatch	Dale River		0.016	5 706	
Mile			ND	2 992	
Mandiakon			ND	ND	

ND – No data; RRP – River Recovery Plan

The identified significant pools are typically the larger permanent pools located within the river reach sections that were established for the River Recovery Plan (RRP) series for the Avon River. Numerous smaller pools have also been identified within both the primary channel and the tributaries of the Avon River however these are unlikely to persist as permanent refuges during the Wet Isolated phase.

4.4.1 Geomorphology and Sediments

The Avon River pool survey conducted by Jim Davies and Associates (JDA 1997) revealed that the spacing of the river pools at 16 to 20 channel widths (3200 to 4000 m) was atypical of meandering channels and was consistent with the pool and riffle type generally described in the literature. The Avon River was found to typify a low power river system with an irregular meander pattern, with the formation of pools where a geological control narrows the river channel (JDA 1997).

Sedimentation of the river pools is significantly impacting on pool volume, with some pools having completely filled with sediment and no longer acting as a summer refuge for aquatic fauna or waterbirds. These include Cold Harbour and Burlong (filled between 1960 and 1985), Mount Hardy, Three Mile, Muresk, Egoline and Deep Dale pools (filled between 1985 and 1996).

Other pools have had their volumes significantly reduced through sedimentation, reducing the available habitat. These pools include Beverley Pool, Speldhurst Pool, Brouns Pool, Fleays Pool, Tipperary Pool, Katrine Pool and Diving Pool.

Pool infilling has occurred due to the predominance of low flow periods where the river velocity is greatest between pool sections and is lowest within pools, resulting in sediment deposition. In order for natural pool scouring to occur extreme flow events (i.e. greater than a 30 year flood event) need to be exceeded (Southwell 1990).

As flood events of the magnitude required to naturally scour pools have not occurred since the RTS, the Department of Water has recommended manual sediment removal from river pools to recover the pool volumes and maintain the ecological and aesthetic values of the pools (DoW 2007a). This is not undertaken for a number of pools of high ecological value primarily due to economic and access considerations.

4.4.2 Water Quality

Water quality monitoring of the river pools has been undertaken in an ad-hoc manner. The Avon River snapshot water quality monitoring included a few pools, however this monitoring is only undertaken during the Flushing and Flooding and Wet Connected flow phases. The primary concerns for the river pools is the water quality of late season flows in the period preceding the cessation of river flow and beginning of the Wet Isolated phase. Water quality at this time is an important indicator of the condition of the pool refuges at the start of the Wet Isolated phase, and will assist in pre-determining their condition for the duration of the summer drought period.

Examination of available water quality data for the Avon River and its reaches reveals the salinity levels of late season flows are typically in the order of 5 000 to 8 000 mg L^{-1} (TDS), which is classified as low

salinity (DoW 2007b). However, evapotranspiration during summer months has the potential to concentrate salinity levels, leading to stress or death of intolerant species.

High nutrient levels have the potential to result in algal blooms during the warmer summer period, which may further lead to development of anoxic conditions. Pools with a large sediment volume, particularly of finer sediment (silt/clay) have been identified as having higher nutrient loads (DoW 2007b).

River pool water quality at the end of the Wet Isolated phase is also an important consideration for fauna dependent on the pools as refuge. Water quality during this period was monitored as part of the Avon River pool survey (JDA 1997), with samples collected in May and June 1996 prior to the commencement of winter flows when the majority of river pools were stagnant. The salinity of the pools ranged between approximately 2 000 mg L^{-1} (Brouns Pool) to 11 000 mg L^{-1} (Beverley and Speldhurst Pools) indicating they had brackish to low salinity levels. Total phosphorous values ranged between 0.017 mg L^{-1} at Lloyd Pool to 0.605 mg L^{-1} at Glen Avon Pool (JDA 1997), with pools that had minor flow at the time of the survey, indicating a permanent seepage or upwelling to the pool, found to have lower total phosphorus concentrations.

4.4.3 Flow Related Issues

Modelling has been undertaken to determine the ability of river flows to scour the pools of the Avon River. Southwell (1993) ran a series of simulations for the Northam - Toodyay reach using a range of low to high magnitude flood events and assuming channel revegetation to establish the impact on pool scour and pool formation. The simulations found that stabilisation of channel sediment through revegetation was important to prevent further infilling of the pools (Southwell 1993).

Maintenance of late season water quality is also important to ensure the persistence of suitable habitat within the permanent summer pools. A key water quality criteria is the salinity level at the beginning of the Wet Isolated phase. An examination of available water quality data reveals an upper salinity level within the range of 5 000 to 8 000 mg L^{-1} (TDS). This salinity level is historically consistent and land and water management within the Avon Arc catchment should aim to maintain, or improve, water quality within this range.

4.5 Aquatic and Riparian Vegetation

The Avon River system supports a variety of fringing plant types, including trees, shrubs, sedges, samphires, herbs and grasses and many different plant communities. This fringing, or riparian vegetation has many functions including:

- *Reducing surface water runoff and erosion;*
- *Stabilisation of sediments and retention of particulate matter;*
- *Protecting riverbanks from boat wash and wave action;*
- *Providing flood and habitat for many animals such as birds, frogs, reptiles and mammals;*
- *Maintaining the diversity of plant and animal species; and*
- *Improving recreational amenity.*

Riparian vegetation provides habitat for a range of species both directly (terrestrial flora and fauna) and indirectly through the provision of woody debris (aquatic fauna). It also provides a fauna movement corridor for many species and is a source of organic material for the river ecosystem.

Additional to ecological importance, riparian vegetation is important for the physical nature of the river channel as it can help prevent bank erosion through the maintenance and/or provision of bank stability. Riparian vegetation along sections of the Avon River has largely been cleared for farming or damaged by livestock grazing. Loss of riparian vegetation through clearing, trampling, grazing, bank erosion etc. has reduced the extent of riparian vegetation along the river, with many areas reduced to small narrow fragmented remnants. Fragmentation of the riparian vegetation has reduced its effectiveness as a fauna movement corridor and increased the exposure to invasions by exotic species.

Other impacts on the riparian vegetation include increasing salinity, nutrient enrichment, flow regulation and invasion by weed species. There is a general consensus within the literature that freshwater flora species of the Avon are gradually being lost and replaced by more salt tolerant species in response to increasing stream and groundwater salinity (Malcolm 2000; WRC 2001; DoE 2005b). Increased nutrients levels are also considered to have contributed to an increase in exotic species.

Other consequences of reduced riparian vegetation are a reduced source of woody debris, decreased bank stability and increased bank erosion. While clearing has had the greatest impact on the distribution and quality of riparian vegetation, changes in flow has also affected vegetation distribution through changes to the available habitat.

4.5.1 Vegetation patterns

The pre-European vegetation and structure of the Avon River was never formally documented, however remnant vegetation along the main river channel and within the tributaries may be used to compile a summary of the vegetation communities that would have occurred.

The study area is classified as part of the South-western Botanical Province (Beard 1981), falling within the Avon Botanical District (Beard 1990). Three common overstorey species are generally found along the Avon River: *Eucalyptus rudis*; *Melaleuca raphiophylla* and *Casuarina obesa*. These species are

generally dominant within the thin riparian band alongside the river channel and its pools, however increasing salinity is resulting in a decline in the salt sensitive *E. rudis* and an increase in the populations of *C. obesa* and *M. rhaphiophylla* which are more tolerant of the saline conditions.

Prior to the removal of channel sediment and vegetation as part of the RTS the braided channels were lightly covered with *M. raphiophylla*. Since the river has undergone stabilisation in some sections, the re-emergence of Melaleuca thickets has been observed on alluvial islands within the channel (Davies *et al.* 1996). Samphires have also been observed to colonise sections of the channel during summer and low flow periods. Common vegetation of the Avon River catchment are listed in Appendix A.

4.5.2 Flow Related Issues

Aquatic and riparian productivity support the functionality of the Avon River food webs, which may in turn affect fish / macroinvertebrate species composition (Section 4.6 and 4.7). Additionally aquatic and riparian vegetation are carbon sources that fuel the ecosystem. The remnant riparian vegetation along the Avon River and its tributaries, along with submerged and emergent macrophytes, also have functional value as fish spawning habitat, predator-avoidance habitat for small species and epiphytic growth substrate. Maintenance of the hydrological connectivity between these zones is required for upkeep of the current community complexity and species diversity.

Maintaining a natural winter and spring flood regime assists in the successful recruitment of seeds, the establishment of seedlings and the development of native riparian plant communities. The distribution of species within the riparian zone and beyond, often reflects differing species water requirements and tolerances to inundation (Pen 1981). For example, *M. rhaphiophylla* exhibits a greater flooding tolerance than *E. rudis* and as such is often found lower in the riparian zone.

Nilsson and Svedmark (2002) provide some basic principles that determine the health and ecological qualities of riparian vegetation:

» *The flow regime determines the ecological processes and the successional evolution of riparian plant communities and ecological processes;*

» *The riparian zone serves as a pathway for redistribution of organic and inorganic material that influences plant communities along rivers; and*

» *The riparian system is a transition zone between land and water ecosystems and is disproportionately plant species-rich when compared to surrounding ecosystems.*

The implications of these basic principles on the riparian vegetation along the Swan-Canning River are that:

» *Maintenance of the flow regime is also important for the riparian vegetation community;*

» *The riparian zone will filter and redistribute organic and inorganic material from the land; and*

» *Riparian zones are naturally more species rich than the surrounding areas and should be retained as such.*

Failure to provide environmental flows to promote recruitment and survival of intact riparian vegetation

communities may result in their degradation, which can increase erosion and further degrade the stream bank, increase sedimentation downstream, and reduce shade and in-stream habitat.

Lewis (2008) reported a large number of pools could support macrophyte dominated regimes provided other conditions such as water depth and nutrient levels were suitable. This is achievable through the delivery of freshwater inputs in the form of riverbank seeps and groundwater upwelling zones.

4.6 Fish Assemblages

4.6.1 Pattern and distribution

Assessment of the fish assemblages of the Avon River and its pools is limited, however the south-west of Western Australia generally has a depauperate fish fauna with a high degree of endemism (Pusey 1989). Biological surveys of the Avon River have identified the following fish fauna of the Avon River (Patten and Easton 1999; RCS 1999):

» *Native freshwater fishes – the western minnow (Galaxias occidentalis) and nightfish (Bostockia porosa);*

» *Native estuarine species - western hardyhead (Leptatherina wallacei) and swan river goby (Pseudogobius olorum); and*

» *Introduced species – eastern mosquitofish (Gambusia holbrooki).*

There are also numerous references to the presence of freshwater cobbler (*Tandanus bostocki*) within the Avon River pools (Walker 1986, in Yates Heritage Consultants 1999; Malcolm 2000; J Fleay, pers. comm. in Viv Read & Associates 2001). It is likely freshwater cobbler are no longer present within the Avon River due to increasing salinity levels. Further, Walker (1986, in Yates Heritage Consultants 1999) reported the presence of trout within the river.

The native species observed within the Avon River are generally widely distributed throughout the Swan region and therefore are not considered to be threatened on a regional basis. However the freshwater species that remain within the Avon River system may be considered locally threatened due to the risk of increasing catchment salinity. The varying salinity of the river pools over summer months may also present problems for freshwater fish populations.

The habitat requirements and spawning characteristics of the fish species recorded within the study area are summarised in Appendix B.

4.6.2 Fish Recruitment and Migration

The freshwater and estuarine fish species of the Avon River are known to migrate to some extent, primarily for breeding, but also for feeding and larval recruitment. The western minnow moves upstream into tributaries to spawn on flooded vegetation between June and late September (Storey *et al.* 2002). As well as the flooding of vegetation, fast flowing waters in tributary streams also appears an important 'stimulus' for successful spawning for the western minnow (Pen and Potter 1991; Storey *et al.* 2002).Nightfish migration occurs in late August to early September, with spawning occurring in flooded

creeks (Pen and Potter 1991).

Monitoring of the fish species biology of the neighbouring Canning River revealed flooding of vegetation and fast flowing waters in tributary streams also appeared an important stimulus for successful spawning of fish species (DoW 2007c).

4.6.3 Flow related issues

Native fish species occurring in the Avon River have a requirement for permanent water of adequate quality and suitable habitat. Both juveniles and adults of the native fish species found in the Avon River system have generalist diets, comprising aquatic and terrestrial insects. The generalist nature of the diets makes it unlikely the diet of any fish species will be affected by alteration to flow regimes.

Several of the species readily invade seasonal creeks to reproduce. Flows for these species are required to enable fish migration upstream into tributaries and seasonal creeks during the breeding season. Migration and reproduction are the aspects most likely to be impacted by an altered flow regime. In order to ensure breeding success and strong recruitment of fish species the predictable winter/spring flooding patterns need to be maintained (Storey *et al*. 2002).

Adequate permanent water during the summer drought is also a prerequisite of Avon River fish species. Late season water quality should also be maintained in order to ensure habitable pool refuge for fishes during the summer drought period. Freshwater lenses and seeps that have been identified as supplying fresh discharges to a number of river pools will also play an important role in maintaining water quality during the summer drought.

4.7 Macroinvertebrates

An important component of the biodiversity of riverine environments is the insects and other groups of invertebrate biota collectively known as macroinvertebrates. They form a fundamental component of the aquatic food web as a major energy source for higher order aquatic and terrestrial fauna such as fish and waterbirds (DoW 2007c). The sensitivity of many species of macroinvertebrates to chemical and physical conditions also makes them important indicators of waterbody health.

The macroinvertebrate community structure of a river system is influenced by several parameters including substrate composition, water temperature, water chemistry, aquatic and riparian vegetation composition, food availability and biotic interactions (ARL 1988). The two main aspects of stream flow regimes that influence these parameters and therefore have an overriding influence on macroinvertebrate community structure within the south-west are seasonality and predictability / persistence (DoW 2007c).

4.7.1 Pattern and distribution

Information on the macroinvertebrate fauna of the Avon River and its pools is limited, and like fish assemblages the macroinvertebrate fauna community of streams in the southwest are depauperate compared to other regions of Australia (Bunn and Davies 1992).

An eighteen-month survey of the macroinvertebrate fauna of Gwambygine Pool at six sites along the

pool is the only published repeated monitoring of macroinvertebrate community structure. The study of Gwambygine Pool revealed approximately 50 species inhabited the pool, with evidence that some species are more prevalent at seasonal and shorter temporal cycles (Savage *et al* unpubl/RCS 1999). The macroinvertebrate fauna observed for Gwambygine Pool is listed in Appendix C.

Key results of the macroinvertebrate survey include:

» *The macroinvertebrate fauna of Gwambygine Pool were classified as cosmopolitan and halotolerant, with similar fauna present in other saline streams within the south-west region. Other fauna that are typically sensitive to polluted or saline water, such as Trichoptera (Caddis fly) and Dipterans, were also observed; and*

» *There were observed differences in the richness and composition of macroinvertebrate fauna on a seasonal basis at Gwambygine Pool. This was attributed to the rapidly flowing nature of the river during winter and spring (even through the pools), compared to the slow to no-flow conditions during summer and autumn.*

Additional macroinvertebrate surveys have been conducted for Boyagarra Pool (Viney and Sivapalan 1999), as well as longitudinal survey of 19 sites by Smith (1996). The study of Boyagarra Pool implied the pool macroinvertebrate community was impoverished as only seven families were recorded however comparison of the survey results for Gwambygine Pool for the period that Boyagarra Pool was surveyed (April) reveals a similarly low number of families present. This is likely due to seasonal influences, with April generally preceding the onset of winter rains and as such water quality conditions (ie. salinity and dissolved oxygen levels) may limit the occurrence of less tolerant families.

The survey by Smith (1996) comprised both pool, and temporary reach and tributary sites; and identified a total of 100 taxa. The survey revealed a longitudinal trend in the composition of macroinvertebrate fauna and indicated habitat played an important role in determining the fauna in conjunction with physio-chemical parameters (Smith 1996).

4.7.2 Water Quantity

Macroinvertebrate fauna of the south-west region show distinct seasonality associated with changes in flow regimes and stream biogeochemistry. Stream biogeochemistry during low flow periods is charactersied by warm water, lower dissolved oxygen, increased salinity and in some cases lower pH, with these conditions reversed during the winter period (Bunn *et al.* 1986). In a study of Jarrah forest community structure Bunn *et al.* (1986) observed distinct summer and winter faunas, with winter rain triggering a relatively rapid transition followed by a gradual return over the summer period.

As with fish species the life cycles of macroinvertebrate species is intrinsically linked to the predictable low summer flows and high winter flows typical of rivers in the south-west of Western Australia (DoW 2007c). A number of species have life cycle stages that are triggered to coincide with stable flow periods and therefore continuation of these features of the flow regime is critical for maintenance of community structure (DoW 2007c).

Therefore macroinvertebrate fauna within the Avon River are sensitive to flow volumes, which are intrinsically linked to water quality.

4.7.3 Water Quality

As with other streams in the south-west of Western Australia the macroinvertebrate communities of the Avon River are influenced by a range of water quality parameters including:

» *Salinity levels;*

» *Dissolved oxygen concentration;*

» *Sedimentation; and*

» *Nutrients and other pollutants.*

The long history of salt within the Wheatbelt landscape (Salama *et al.* 1993) and the presence of resilient macroinvertebrates indicate the fauna of the Avon are adapted to a saline environment (Halse *et al.* 2002). Halse *et al.* (2002) suggests that composition of the macroinvertebrate fauna of the Avon River is largely predictable along its length due to its uniform brackish to saline water quality.

Kendrick (1976) reported the molluscs *Westralunio carteri* and *Plotiopsis australis* disappeared or declined from the Avon River at salinities < 10,000 mg L^{-1}. Hart *et al.* (1991) predicted that severe salinisation of rivers may favour a shift from an insect dominated to crustacean dominated system, as crustaceans as a group are the most salt tolerant of the macroinvertebrates. Predators such as beetles may also be adversely impacted due to a change in their available food sources.

4.7.4 Flow related issues

While the macroinvertebrate community structure of the Avon River may have adapted to the distinct seasonality and the climatic extremes of the Wheatbelt region, any permanent changes to the flow regime may result in a shift in the community composition. The relatively short life cycle and generation times of macroinvertebrate fauna also suggest that community level responses may be as rapid as hydrological change.

As with fish species the provision of adequate permanent water of habitable water quality during the summer drought is a prerequisite of Avon River macroinvertebrate biota. Freshwater lenses and seeps that have been identified within the catchment act as biodiversity hotspots for macroinvertebrates.

5. Impact of Further Catchment Storages

5.1 Overview

Catchment storages or farm dams play an important role in Australian agriculture by capturing runoff that may be used during low rainfall periods (National Water Commission 2007b). Farm dams include both on and off-stream storages, however for the purposes of this report, catchment storages refer to off-stream storages. These off-stream storages are not located across drainage paths and are filled by runoff or groundwater interception, or diversion from surface or groundwater sources. Off-stream storages intercept water that would otherwise flow to the stream and therefore impact on downstream water flows in a similar manner as on-stream storages.

The impact of individual off-stream storages is small however the cumulative impact of a large number of farm dams can be significant. The cumulative impact is generally greatest on low flows and can cause the delay of the wet season or prolong dry periods (National Water Commission 2007b). These impacts occur as the first significant rains following the dry period are intercepted by farm dams rather than contributing to stream flows.

While there is no existing data on the impact of increasing catchment storages on the annual hydrological regime of the Avon River, a number of studies examining the impact of farm dams on surface water flows have been undertaken throughout Australia.

A South Australian study by Teoh (2003) found that farm dam development impacted on surface water flows in the Onkaparinga River catchment and the resultant modification to flow regimes may be impacting water dependent ecosystems. The study found that farm dams in the Onkaparinga River catchment capture 5% of median annual flow, but 16% of the low flows (10th percentile) across the catchment. Further the impact on some of the tributaries was much higher with median flows reduced by 20% and low flows (10th percentile) reduced by 99% in the Mitchell Creek catchment due to farm dams (Teoh 2003). Further, within one of the drainage sub-catchments retention of 21% and 23% of the first month of winter flow was observed during a median flow year and low flow year respectively.

In a similar study within South Australia's Upper Marne River Catchment, Savadamuthu (2002) found the impact of farm dams was most significant during late wet season / early summer due to pumping of river water for irrigation and also during late summer / early winter when the dams are relatively empty. This timing was likely to be significant to water dependent ecosystems. Savadamuthu (2002) also found farm dams reduced the duration of low and medium runoff events and reduced the median annual adjusted runoff with these impacts exacerbated during dry years.

Further studies from Victoria conducted within the Murray Darling Basin have estimated that, under Victorian conditions, farm dams may decrease annual streamflow by 0.84 ML per ML of farm dam storage, with this impact ranging from 0.24 ML/ML to as high as a 1.2 ML/ML decrease (National Water Commission 2007b).

Within the Murray Darling Basin it has been estimated that the combined farm dam storage capacity is approximately 2,200 GL. It was estimated that annual streamflow is reduced by 0.66 ML per ML of farm dam storage, resulting in an estimated streamflow reduction of 1,900 GL yr^{-}, (G. Scholz, DWLBC, pers.

comm., 2005 in McMurray 2006).

The following impacts of farm dam storages as a result of changes to the flow regime were identified in a recent South Australian study and are listed in Table 5:

Table 5 Impact of farm dams on flow regimes

Changes to Flow	Impact
Up to 10% of annual stream flow removed	Minimal Impact
10-20% stream flow removed	Impacts on sensitive species
20-40% stream flow removed	Significant Impact
>50% stream flow removed	Major environmental change within 25 years

5.2 Potential Impact on Environmental Attributes

5.2.1 Hydrology

The tributaries of the Avon River contribute variably in terms of quantity and quality of flow and therefore interception of a significant proportion of inflows from fresh water sources or tributaries that have higher water quality may impact on the downstream river ecology.

If flow in tributaries that contribute low nutrients and salinity levels to the main Avon River is reduced this will invariably lead to a decline in the Avon River water quality and increased salinity. Similarly if any perennial freshwater seeps identified within the catchment are intercepted by farm dams this will lead to reduced freshwater inflows and increasing river salinity (van Dijk *et al*. 2006).

Further, an increase in the number and capacity of catchment storages may result in a delay in the onset of wet season flows within a sub-catchment and for the Avon River. This occurs as a result of the filling of storages during the period that the catchment is wetting up, leading to reduced contribution to the stream. The water quality within the pools following the extended dry period of the Wet Isolated phase is likely to be marginal unless the pool is sustained by a freshwater seep. It is therefore undesirable for the wet season flows to be delayed as this is likely to be detrimental to aquatic fauna inhabitants.

An increase in the number of on-stream dams also has the potential to disrupt the connectivity of the stream, through regulation of stream flow and transport of organic matter along the rivers longitudinal profile.

In particular, on-stream dams that do not have flow bypass structures may result in an early start to the Wet Isolated Phase due to damming of the late season flows and similarly delay the onset of the Wet Connected Phase. As stated previously in Section 4.1 the timing of these flows (late summer/early winter) are important for water dependent ecosystems and in particular the aquatic biota relying on the

river pool as a summer refuge.

5.2.2 Geomorphology

The Avon River has in recent years carried large sediment loads. Increasing the volume of catchment storages within the catchment is not expected to have a major impact on geomorphology as they are unlikely to reduce the magnitude of peak flow events that are the primary driving force of channel geomorphological change.

5.2.3 Water Quality

An increase in catchment storages may not only lead to a reduction in streamflow volumes but may result in a further decline in water quality in the Avon River catchment. The impact on water quality will be dependent on the timing and spatial distribution of catchment runoff.

An increase in the number of dams has the potential to impact the water quality within the river pools during two key periods:

» *The start of the Wet Isolated Phase; and*

» *The beginning of the Wet Connected Phase.*

5.2.4 River Pools

The construction and siting of catchment storages within the Avon Arc catchment is largely unregulated which has the potential to further impact on the ecological values of the river pools. The cumulative impacts of existing and potential catchment storages within a sub-catchment and the greater Avon Arc catchment should be considered to determine if the capacity of the storages may adversely impact the environmental significant river pools. Siting of catchment storages should also be regulated to ensure that they are not intercepting freshwater lenses or seeps that are important to maintain the water quality of some river pools during summer periods. Further, where there are a high proportion of large farm dams these may store volumes of water that may have a significant impact on the ecology of the river pools.

5.2.5 Aquatic and Riparian Vegetation

An increase in catchment storages may lead to a decline in the biodiversity of the riparian zone of the Avon River through the potential for increased salinity of river flows and the summer pools, which may result in further decline in the population of *E. rudis*.

If an increase in catchment storages further impacts on the salinity levels in the stream there is potential for the freshwater riparian species to retract further and be limited to those areas where freshwater seeps occur within the catchment. It is also possible that reduced low season flows and poorer late season water quality may encourage further dominance of salt tolerant species within riparian communities of the river pools.

An increase in the quantity and capacity of catchment storages is considered more likely to impact upon low and median flows (Section 5), rather than high and overbank flows. These peak flows are

considered important as a number of species of riparian vegetation are dependent on seasonal inundation for germination and seed dispersal.

5.2.6 Fish Assemblages

Additional catchment storages within the Avon Arc catchment may delay the onset of early winter flows which may result in stress of fish species seeking refuge in the winter pools over summer. Further, if the capacity of catchment storages is greatly increased there may be a delay in the discharge patterns that form key biological cues for successful reproduction.

5.2.7 Macroinvertebrates

Additional catchment storages within the Avon Arc catchment may delay the onset of early winter flows which may result in further decline of the water quality within river pools, stressing macroinvertebrate fauna. Further, if catchment storages are sited to intercept freshwater lenses or seeps they may impact species that rely on the freshwater resource.

6. Flow Objectives

Catchment flow objectives have been determined for the following environmental attributes described within Section 5 of this report:

» *Hydrology;*

» *Geomorphology;*

» *Water Quality;*

» *River Pools;*

» *Aquatic and Riparian Vegetation;*

» *Fish Assemblages; and*

» *Macroinvertebrates.*

Hydrology objectives focus on maintaining a naturally variable flow, as well as regulating the construction and siting of storages. These factors influence geomorphological and river pool objectives which rely on variation in flow to maintain sedimentation characteristics, channel dynamics and aquatic life.

Water quality focuses on the maintenance of healthy waterways and objectives focus on preventing poor water quality that inturn impact aquatic and riparian vegetation, fish assemblages and macroinvertebrates.

River pools are highly valued in the environment and the flow objectives specific to these assets are based upon the need to maintain their existing condition and function. This will ensure their value within the environment does not diminish. Furthermore, aquatic and riparian vegetation, fish assemblages and macroinvertebrates all require healthy waterways to survive and flourish.

The purpose of defining flow objectives is to identify the key factors and objectives that will enable the achievement of sustainable environmental flow through the Avon Catchment. These flow objectives are detailed in Table 6.

Table 6 Avon Catchment Flow Objectives

Environmental Attribute	Objective
Hydrology	» Protect groundwater resources surrounding River Pools to ensure continued discharge of low salinity groundwater. » Minimise the impact of catchment storages on flow initiation by ensuring on-stream dams have by-pass structures. » Limitation of off-stream dam catchments. » Prevent flow withdrawal/pumping from the river channel to top up catchment storages during late season flows and summer periods. Channel withdrawal should only be allowed during the Wet Connected phase.

Environmental Attribute	Objective
Geomorphology and Sedimentation	» Maintain significant flows to maintain the active channel morphology. » Flows of a significant magnitude to scour accumulated material from river pools.
Water Quality	» Tributaries that are identified as having higher water quality (i.e. low salt and nutrient concentrations) should be subject to lower pressure from catchment storages where possible to prevent the degradation of late season water quality within these tributary inflows. » Identify recharge and discharge freshwater seepage zones. » Catchment storages should not be constructed within freshwater lenses and seeps to the Avon River or its pools. » Maintain sufficient late season fresh water flows in order to ensure that salinity of river pools does not increase above 8 000 mg/L TDS at cease-to-flow. » Maintain late season flows of sufficient water quality in order to reduce the risk of nutrient enrichment and anoxia of the river pools.
River Pools	» Maintain flows of a sufficient magnitude to scour sediment filled pools. » Flushing flows in winter are required to reduce the nutrient load in pools from the accumulation of organic and inorganic material. » Maintain the water quality of late season flows to ensure suitable habitat during the Wet Isolated phase. » Construction and siting of catchment storages should be regulated to minimise impact on early winter flows. » Catchment storages should not intercept permanent freshwater lenses or seeps. » No diversion or pumping of river flows during the late wet season/early summer, or for the duration of the Wet Isolated phase. » On-stream storages should be constructed with bypass valves to enable bypass of early winter flows.

Environmental Attribute	Objective
Aquatic and Riparian Vegetation	» Allow sufficient flow 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 maintenance and restoration 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.
Fish Assemblages	» Maintenance of adequate water quality, particularly during late season flows, to ensure survival of fish species. » Maintenance of permanent freshwater pools during summer months to ensure survival of fish species. » Maintenance of freshwater flows from sand lenses and seeps at sufficient replenishment rates to avoid anoxic conditions for pools in summer. » Winter spates and zero flow days to manage introduced species. » Sufficient flows to retain a minimum depth of 0.2 m in main stem reaches throughout August-October, to enable reproductive migration and spawning alongside streamside vegetation. » 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. » Maintain higher baseflows in spring to inundate emergent and trailing streamside vegetation for fish spawning habitat, » Maintain shallow backwater areas as nursery, predator avoidance, and habitat areas for juvenile fish as well as areas to avoid high flows in the main channel. » Flows to inundate undercuts to provide fish habitat for small-bodied fish species. » Provide sufficient water to prevent sediment aggregation to maintain habitat and functionality of pools for fish. » Protection of flow pulses that provide important biological cues for fish species. » 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.

Environmental Attribute	Objective
Macroinvertebrates	» Allow sufficient flow 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).

7. Discussion

7.1 Key Environmental Assets

Through this desktop assessment of the environmental attributes, flow related issues and preliminary flow objectives for the Avon Arc catchment, a number of environmental assets that are key to maintaining and enhancing the ecological values of the Avon River have been identified. These key environmental assets play an important role in the provision of habitat and maintenance of biodiversity within the system. These include:

» *River Pools – The river pools provide a permanent water source during the summer drought, acting as an important refuge for both aquatic and terrestrial fauna.*

» *Fresh sub-catchments – The fresher sub-catchments of the Avon River (including the Dale River) are important in providing a fresh water source to the river and diluting the salt concentration from other sub-catchments. These fresh sub-catchments help to maintain the biodiversity of the aquatic fauna and the species composition of the aquatic and riparian vegetation.*

» *Freshwater lenses and seeps – There is evidence of numerous freshwater lenses and seeps occurring throughout the Avon Arc catchment, providing permanent sources of freshwater to both the river pools and to the river bed (Lewis 2008). These sources of freshwater play an important role in maintaining the species composition of fauna and vegetation within the Avon by: maintaining the quality of the river pool habitat during the harsh summer months; acting as hotspots for aquatic biodiversity; providing freshwater source to aquatic and riparian vegetation.*

» *Remnant riparian vegetation – The remnant riparian vegetation of the Avon River provides an important role in the provision of habitat, prevention of bank erosion, regulation of water temperature, and maintenance of biodiversity.*

Key environmental assets should be protected in future water resource management and planning decisions in order to maintain and enhance the ecological values of the Avon Arc.

7.2 Environmental Water Requirements

The identification of environmental water requirements requires recognition of ecological values of the system under investigation. For relatively undisturbed ecosystems, it is clear that the aim is to protect existing natural ecological values. For ecosystems, which have already suffered disturbance due to regulation and/or as a result of land use changes, the aim is not so clear. The options are to:

» *Maintain the current ecological values;*

» *Maintain and / or enhance current ecological values;*

» *Identify the likely pre-existing natural ecological values and determine the key values that environmental water requirements should aim to re-establish; or*

» *Provide for a combination of current ecological values and key pre-existing natural ecological values.*

The aim of any future environmental water requirement investigations for the Avon Arc catchment should

not be to re-establish the environmental values of the system pre the river training scheme (RTS), but to instead, aim to maintain and enhance the existing ecological values.

Ecological values that are water or water resource dependent include:

- *Biodiversity;*
- *Ecological processes and functions;*
- *Wetland vegetation;*
- *Phreatophytic vegetation (vegetation accessing the groundwater table);*
- *Riverine vegetation;*
- *Aquatic invertebrates (including subterranean fauna); and*
- *Vertebrates (e.g. fish, waterbirds).*

7.3 Knowledge Gaps

There are a number of knowledge gaps regarding the identified ecological values and environmental assets that need to be resolved before environmental water requirements may be determined for the water resources of the Avon Arc catchment.

Table 7 Key knowledge gaps and preliminary information requirements

Knowledge Gap	Preliminary Information Requirements
Surface water quantity	Discharge measurements are currently made at established gauging stations however these sites are spatially distributed and additional stations should be established, particularly on the major tributaries. This data is needed to assess geomorphological flow requirements, inundation frequencies, riparian vegetation and aquatic fauna water requirements.
Surface water quality	Surface water quality monitoring has been undertaken in an ad-hoc manner throughout the catchment. Further water quality data is needed to estimate nutrient loadings from the various tributaries, to establish nutrient sources (land use, riparian vegetation) and to establish aquatic fauna response to water quality conditions. In particular targeted monitoring should be undertaken to examine trends in water quality parameters (nutrients, salinity) with emphasis on the late season/end of Wet Connected phase and throughout the summer drought during the Wet Isolated phase.
Freshwater seepage zones	There is some water quality data and substantial anecdotal evidence of the existence of numerous sandplain seeps and upwelling zones that contribute freshwater to the pools and the bed of the Avon River. These sites should be identified and mapped throughout the catchment and their influence on water quality and biodiversity (aquatic fauna and vegetation) established.

Knowledge Gap	Preliminary Information Requirements
Goundwater hydrology and quality	There is limited information on the hydrogeological resources of the Avon region. Further information is required about the quantity and quality of groundwater flows to sub-catchments and to the river pools. This includes more comprehensive compartmentalized groundwater mapping adjacent to the Avon River as an extension to the recent work by Lewis (2008).
Distribution and abundance of species	Further information is required about the distribution of fish and macroinvertebrate species.

7.4 Priority catchments

The gap analysis illustrates that substantial information is lacking to definitively set environmental flow objectives across the Avon Arc catchment in a 'holistic' manner. A goal to fill all knowledge gaps across all of the catchments is unrealistic and therefore priority catchments have been identified (Table 8). These priority catchments correspond to those catchments that have been identified as having higher water quality (either fresh water or low nutrients) than other sub-catchments. It is recommended that investigations be focused on these catchments initially and a review of the knowledge gaps be undertaken once further sub-catchment specific information is established. It should be noted it will also be important to undertake specific investigations within the more saline sub-catchments (i.e. Mortlock River), however the focus is on the fresher catchments in an attempt to maintain the ecological values of the Avon that are dependent on fresh water.

Table 8 Priority Catchments

Priority Catchment Name	Rationale
Dale River	The Dale River contributes fresher flows to the Avon River than the other major tributaries, primarily due to Christopher Brook (see below). The water quality of the Dale River is thought to contribute to the good health of Gwambygine Pool downstream from its confluence with the Avon. The Dale River is also the western most catchment receiving higher mean annual rainfall and with less clearing than other sub-catchments.
Christopher Brook	Christopher Brook flows into the Talbot Brook just above the junction with the Dale River and is a relatively freshwater stream.
Toodyay Brook	Toodyay Brook was identified as contributing tributary inflows of reasonable water quality to the Avon River (DoW 2007b).
Mackie River	The Mackie River was identified as contributing water of a reasonable quality with regards to nutrients to the Avon River (DoW 2007b).

7.5 Water Resource Management

The regulation of dam construction within the Avon Arc is primarily undertaken by Local Government.

The Avon River catchment is a Proclaimed Surface Water Area under the *Rights in Irrigation Water Act 1914*. Under the Act proposals for sub-division or development which interfere with a water course, wetland or groundwater are referred to the Department of Water. These types of proposals include any application for the construction of on-stream dams.

For the construction of off-stream dams no approval is required provided the flow of water in a watercourse, or the amount of water in a wetland, is not diminished or there is no significant adverse effect on the quality if water, or any ecosystem, in a watercourse or a wetland (Section 5B of the Act).

As the assessment of dams is undertaken on an individual basis, the cumulative impact of dams within a sub-catchment or greater catchment would likely not be considered under the provisions of the Act.

When considering applications for future catchment storages local government should ensure the construction of the catchment storages do not lead to adverse environmental impacts. The ad hoc manner with which catchment storages are considered within the planning process does not consider the cumulative impact of storages, or the impact on the sustainable flow requirements within a sub-catchment or the greater Avon Arc catchment.

To ensure the long term sustainability of the identified ecological values and maintenance of environmental water requirements within the Avon Arc catchment, Local Governments should regulate the construction and siting of farm dams in the following instances:

» *Proposed dam exceeds 10 ML in capacity;*

» *Cumulative capacity of dams within the sub-catchment exceed 15% of sub-catchment stream flow;*

» *Proposed dam to be sited within freshwater lense or seep; and*

» *Proposed dam is located within a high priority sub-catchment.*

7.6 Land Use Planning

In undertaking land use planning decisions within the Avon Arc catchment Local Government should also consider the environmental water requirements of the Avon River and its tributaries. Particular land use planning decisions that should consider environmental water requirements include:

» *Urban development – urban development has the potential to generate additional runoff, due to higher impervious areas, and high nutrient loadings;*

» *Semi-rural development – applications for sub-division of larger parcels of land into semi-rural development have the potential to increase the number of catchment storages as well as the nutrient export from the land; and*

» *Near river development – development applications within a predetermined buffer zone (i.e. 500 m) to the Avon River or its tributaries that have the potential to adversely impact environmental water requirements through the interception of freshwater sources, acting as a point source of poor water*

quality and/or impacting the water regime.

The above forms of developments should undertake detailed environmental and hydrologic assessment with consideration of the impacts of the development on the downstream environment. In particular the hydrologic assessment should consider the volume, water quality and timing of any discharges to the Avon. These studies should also consider the potential changes to stream flow as a result of any catchment storages. These studies should form part of a Water Management Strategy as discussed further within the recently released *Better Urban Water Management* guideline (WAPC 2008). While the guideline is intended for use within urban development areas of the Swan Coastal Plain, the principles of managing water within the context of land use planning are relevant within the Avon Arc.

The Avon Arc Sub-Regional Strategy provides a framework for the long term land use within the Avon Arc catchment. This document may be used to identify areas where future land use pressures may impact on the identified ecological values and environmental assets of the Avon Arc.

8. Conclusions and Recommendations

The water dependent ecosystems of the Avon River are considered to be well adapted to a fluctuating environment due to their occurrence within a region that has highly variable inter annual river flows in response to climate variations. Major threats to the biodiversity of these ecosystems within the Avon Arc catchment are presented by increasing salinity, sedimentation, nutrient enrichment and a changing flow regime.

This desktop assessment has focussed on flow related issues that may occur as a result of an increase in the number and/or capacity of catchment storages within the Avon Arc catchment. In undertaking management and planning decisions consideration should also be given to other flow related issues such as climate change and land use change.

This desktop review has identified a number of environmental values and key environmental assets of the Avon Arc catchment. To ensure the long term sustainability of the identified ecological values and attributes, there are a number of key environmental assets that should be protected within the context of future land and water planning and management in the Avon Arc catchment. Consideration should also be given to the identified environmental values and attributes when undertaking any planning decisions within the catchment.

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Appendix A

Vegetation Species

Common Plant Species of the Avon River Catchment

Latin names and vernacular names of plant species commonly found along the Avon River[2]

Latin Name	Vernacular Name
Tree Species	
Acacia saligna	Orange Wattle
Allocasuarina huegliana	Rock Sheoak
Banksia priornotes	Acorn Banksia
Casuarina obesa	Swamp Sheok
Eucalyptus kondinensis	Kondinin Blackbutt
Eucalyptus loxophleba var loxophleba	York Gum
Eucalyptus loxophleba var lissophloia	York Gum
Eucalyptus rudis	Flooded Gum
Eucalyptus salicola	Salt Gum
Eucalyptus salmonophloia	Salmon Gum
Eucalyptus sargentii	Salt River Gum
Eucalyptus sugrandis subsp alipes	Swamp Mallee
Eucalyptus yilgarnensis	Yorrell
Eucalyptus Wandoo	Wandoo
Macrozamia riedlei	Zamia
Pittosporum phylliraeoides	Native Apricot
Shrubs (>2m height)	
Acacia acuminata	Jam Wattle
Acacia colletioies	Wait-a-While Wattle
Acacia meisnerri	
Acacia merrallii	Merrall's Wattle
Acacia microbotrya	Manna Wattle
Acacia pulchella	Prickly Moses
Astartea fascicularis	
Callistemon phoeniceus	Lesser Bottlebrush

[2] Refs WRC(2001) Riparian zone vegetation in the Avon catchment, Water Note 31.
WRC (2003) Revegetating with native grasses in the Avon catchment, Water Note 24.

Latin Name	Vernacular Name
Grevillea paniculata	
Grevillea vestitia	Rusty Grevillia
Hakea preissii	Needle Bush
Jacksonia furcellata	Grey Stinkwood
Jacksonia sternbergiana	Stinkwood
Leptospermum erubescens	Roadside Teatree
Melaleuca acuminate	
Melaleuca cuticularis	Saltwater Paperbark
Melaleuca hamulosa	
Melaleuca lateriflora var lateriflora	
Melaleuca preissiana	Stout Paperbark
Melaleuca rhaphiophylla	Swamp Paperbark
Melaleuca thyoides	Salt Lake Honey Myrtle
Melaleuca uncinata	
Melaleuca viminea	Mohan
Santalum acuminatum	Quandong
Santalum spicatum	Sandalwood
Shrub (<2m height)	
Allocasuarina humilis	Dwarf Sheoak
Atriplex amnicola	River Saltbush
Atriplex bunbuuryana	Silver Saltbush
Artiplex codonacarpa	Dwarf Saltbush
Artiplex holocarpa	Pop Saltbush
Artiplex nummularia	Old Man Saltbush
Artiplex paludosa	Marsh Saltbush
Artiplex stipitata	Kidney Saltbush
Artiplex vesicaria	Bladder Saltbush
Artiplex semibaccata	Creeping Saltbush

Latin Name	Vernacular Name
Astroloma glaucescens	
Banksia bipinnatifida	
Enchylaena tomentosa	Ruby Saltbush
Frankenia pauciflora	Sea Heath
Maireana brevifolia	Bluebush
Melaleuca thymoides	A Myrtle
Rhagodia spinescens	Spring Saltbush
Grass Species	
Agrostis avenacea	Blown Grass
Amphibromus nervosus	Swamp Wallaby Grass
Amphipogon	Turbinatus
Aristida contorta	Bunched Kerosene Grass
Aristida holathera	Great Kerosene Grass
Austrodanthonia setacea	Smallflower Wallaby Grass
Austrodanthonia caespitosa	Wallaby Grass
Autrostipa elegantissima	Featherspear Grass
Austrostipa macalpinei	Golden Speargrass
Austrostipa pycnostachya	Salt Speargrass
Austro tenuifolia	
Austrostipa trichophylla	
Chloris truncata	Windmill Grass
Cymbopogon ambiguus	Scentgrass
Enteropogon acicularis	Curly Windmill Grass
Eragrostis australasica	Canegrass
Eragrotis elongata	Clustered Lovegrass
Leptochloa fusca	Brown Beetle Grass
Microlaena stipoides	Weeping Grass
Neurachne alopecuroidea	Foxtail Mulga Grass

Latin Name	Vernacular Name
Polypogon tenellus	
Puccinellia stricta	Marsh Grass
Sporobolus viriginicus	Native Marine Couch
Themeda triandra	Kangaroo Grass
Triraphis mollis	Needle Grass
Herb Species	
Cheilanthes distans	Bristly Cloak Fern
Juncus pallidus	Pale Rush
Sarcocornia quinqueflora	Beaded Samphire

Appendix B

Fish Species

Habitat Requirements and Spawning Characteristics

Fish migration	Species	Habitat requirements	Spawning	Spawning habitat	Reference	Endangered Status	Picture
Potamodromous species	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.	Allen (1989)	Not listed in EPBC Act	
Potamodromous species	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.	Allen (1989)	Not listed in EPBC Act	
Potamodromous species	Freshwater cobbler *Tandanas bostocki* No longer in Avon due to salinity	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 20-24ºC	Build a 'nest' snagged under submerged rocks or woody debris. Protected by the males.	Allen (1989)	Not listed in EPBC Act	
Estuarine species	Swan River Goby *Pseudogobius olorum*	Inhabits muddy areas and seagrass beds in the upper reaches of estuaries. It is also known to penetrate upstream into freshwater and may remain there for extended periods of time.	Spawns during spring in the upper reaches of estuaries (<30% salinity)	Aquatic vegetation is plentiful	Larson (2001)	Not listed in EPBC Act	

Fish migration	Species	Habitat requirements	Spawning	Spawning habitat	Reference	Endangered Status	Picture
Estuarine species	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.	Pavlov et al. (1988)	Not listed in EPBC Act	
Introduced species	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	Page and Burr (1991)	Not listed in EPBC Act	
Introduced species	Goldfish/Carp Carassius auratus	Still or slow flowing waters. Able to withstand high temperatures and low oxygen	Not identified	Quiet backwaters of rivers, swamps and lakes.	Kottelat (1993)	Not listed in EPBC Act	

Appendix C

Macroinvertebrate Species

Gwambygine Pool (1996/7)

Phylum	Order/class	Family
Annelida	*Nematoda* sp.	
	Oligochaeta Tubificidae sp.	
	Hirudinea sp.	
Mollusca	*Bivalvia Fluviolorata subtorta*	
	Bivalvia Hyriidae westralunio	
	Gastropoda Pomatiopsidae Coxiella glabra	
	Gastropoda Pomatiopsidae Coxiella striatula	
	Gastropoda Planorbidae gyraulus	
Arachnida	*Hydrachnidae* sp.	
	Hydracarina sp.	
	Eylaidae sp.	
Crustacea	*Cladocera*	*Chydoridae*
		Daphniidae Daphniopsis pusilla
	Ostracoda	*Mytilocypris*
	Copepoda	*Sulcanus conflictus*
		Harpacticoida sp.
		Cyclodoida
	Amphipoda	*Austrochiltonia subtenuis*
		Ceinidae
	Decapoda	*Palaemonetes australis*
		Cherax quinquecarinatus
Insecta	*Colembolla*	
	Coleoptera	*Carabidae*
		Gyrinidae
		Hydrophilidae Berosus
		Hydrophilidae non-Berosus sp. A and sp. B
		Hydrophilidae Berosus amoenus
		Hydrophilidae Hybogralius sp.
		Hydraenidae Ochthebiinae sp.

Phylum	Order/class	Family
		Dytiscidae Antiporus gilberti
		Dytiscidae Nectorosoma penicilatus
		Dytiscidae Lancetas lanceolatus
		Dytiscidae Macrogyrus reichei?
		Dytiscidae Aulonogyrus strigosus
		Dytiscidae Magaporus howitti
		Dytiscidae Platynectes sp.
		Dytiscidae Paroster sp.
	Trichoptera	*Leptoceridae Oecetis* sp.
		Leptoceridae Notalina spira
		Leptoceridae Triplectides australis
		Hydroptilidae sp.
		Lepidoptera sp.
Odonata	*Zygoptera*	*Coenagrionidae Xanthagrion erythroneurem*
		Coenagrionidae Ishneura sp.
	Anisoptera	*Libellulidae Pantala flavescens*
		Libellulidae Orthetrum caledonicum
		Corduliidae Hemicordulia tau.
Diptera		*Chironomidae Procladius paludicola*
		Chironomidae sp.
		Tabanidae Tabanini
		Stratiomyidae Odontomyia?
		Ephypridae sp.
		Ceratopogonidae Nilobezzia sp.
		Ceratopogonidae Monohelia sp.
		Culcidae Anophelini
		Culcidae Culicini
		Stratiomyidae Odotomyia?
Hemiptera		*Corixidae Agraptorixa parvipunctata*
		Corixidae Micronecta sp.
		Notonectidae Anisops thienemanni

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