WATER CORPORATION

ENVIRONMENTAL WATER REQUIREMENTS
OF ANGOVE CREEK
& LIMEBURNERS CREEK

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EXECUTIVE SUMMARY

Environmental water requirements (EWRs) of Angove Creek and Limeburners Creek were assessed in the context of COAG water reforms and ANZECC/ARMCANZ principles. The "holistic" methodology; a protocol considered "best practice" for Australian systems was used for the assessment. In the holistic method, EWRs for water-dependent ecosystems of the creeks were assessed in the context of both historic and existing hydrology. A number of important components of the ecosystems requiring water allocation were considered: channel morphology, the maintenance of Angove Lake, riparian vegetation, fish, benthic macroinvertebrates and ecological processes.

Angove Creek Catchment

Angove Creek is a major drainage system of the ecologically-important Two Peoples Bay Reserve, approximately 40 km east of Albany. Abstraction from Angove Creek for water supply has varied from about 800 ML/annum (i.e. ~30% of mean annual flows) prior to 1981, to a current rate of about 1,600 ML/a (i.e. ~60% of MAF). The proposed abstraction of 1,800 ML/a (and up to 2,200 ML/a in wet years) represents 67 – 82% of MAF. Analysis of the historic flow record shows that abstraction of 2,200 ML/a would exceed total annual flows in some drier years (e.g. 1969, 1974, 1975, 1976 and 1980).

EWRs were determined in the context of the desired future state (DFS) of Angove Creek. The DFS for the creek was considered the existing ecological values protected at a low level of risk. Current EWRs for Angove Creek, for this DFS, were estimated to be about 882 ML/a in "average" years, increasing to 902 ML/a in "wet" years. In wet years, a "flushing flow" of about the capacity of the active channel (over 18 hours duration) should be allowed to flow through the system; based on the capacity of the existing water supply system, proposed extraction rates will have little influence on the magnitude of flood flows. These EWRs, which assume baseflows of about 35 ML/month, are considered sufficient for fish passage and migration, survival of aquatic benthic invertebrates, and maintenance of water levels in Angove Lake. Much of the riparian vegetation is probably maintained by groundwater rather than by directly intercepting water from the channel.

The management of abstraction is critical for a number of environmental reasons. The creek must never run dry due to abstraction. The rates of abstraction should be managed to ensure there is minimal bank slumping. The estimated EWRs are essentially a "best scientific guess" therefore it is important the system is monitored throughout the implementation of any changed abstraction regime. Monitoring should be adaptive and include parameters such as the health of riparian vegetation, recruitment of fish, water quality, water-levels in Angove Lake and pool aggradation/bank slumping.

Limeburners Creek Catchment

Limeburners Creek is a first-order drainage system southwest of Albany. The creek has a depauperate aquatic fauna (no fish were collected and only few macroinvertebrates). As such, it was concluded that there were no important water-dependent ecosystems in the creek that were not well represented elsewhere on the south coast. The vegetation of the Creek however, was largely undisturbed and considered more reliant of local groundwater than direct interception of creek water. The DFS was also considered to be the protection of existing ecological values at a low level of risk. In this context, and on the basis of analysis of historic flows, any modified regime that maintained perennial flows in Limeburners Creek would be considered sufficient to meet current EWRs.
SUMMARY

Background

Environmental water requirements (EWRs) were assessed for Angove Creek east of Albany and Limeburners Creek to the south-west. The ecological importance of the Angove Creek system is due, in part, to an “A Class” Nature Reserve (Two Peoples Bay Nature Reserve) in the downstream catchment, which was initially established to protect the Noisy Scrub-bird (*Atrichornis clamosus*) and its habitat. EWRs were considered in the context of COAG water reforms and ANZECC/ARMCANZ principles and assessed using a “holistic” methodology; a protocol considered “best practice” for Australian systems (Arthington 1999). In this method, EWRs for water-dependent ecosystems of the creeks were assessed (spatially and temporally) in the context of both historic and existing hydrology. The desired future state (DFS) for the Creek was considered to be protection of the current condition / values at a low level of ecological risk. Important flow characteristics of the ecosystems requiring specific water allocation included: flows for riparian vegetation maintenance and inundation, flows to maintain levels in downstream lakes (*e.g.* Angove Lake), sufficient flows for fish passage and migration, adequate flows for benthic invertebrates and channel maintenance flows.

Legislative Framework

There are several key policies affecting water allocation in Western Australia. At present, water allocation is recognised under the *Rights in Water and Irrigation Act (1914)*, however the water industry is committed to re-structure through COAG water reforms. The COAG Water Reform Framework Agreement obligates the water industry to consider the environment as a legitimate consumer of water. Further, the National Principles for the Provision of Water for Ecosystems (ANZECC/ARMCANZ 1996) establish a framework for water allocation. This allocation is typically determined in a context of competing (*i.e.* agriculture, industry, social and environment) users.

EWRs are based on the premise that the environment has a right to water; that is it has to be regarded as a legitimate user. The terminology used in this report is based on that used in the *National Principles for the Provision of Water for Ecosystems* (ARMCANZ/ANZECC 1996) where:

- **Environmental Water Requirements** (EWRs) describe water regimes (spatial and temporal) needed to sustain the ecological values of water dependent ecosystems at a low level of risk.

- **Environmental Water Provisions** (EWP) are that part of the environmental water requirements that can actually be met after consideration of social and economic factors.

In Western Australia, the Water and Rivers Commission (WRC) uses a “Draft Environmental Water Provisions Policy” as a context for water allocation. In the formulation of this policy, the Commission was guided by the “National Principles for the Provision of Water for Ecosystems” (ARMCANZ/ANZECC 1996). At present, there are three nominal levels of Allocation Plans forming the basis of decisions on water allocations:

(i) Regional Allocation Plans- those that guide overall management of water resources for a region by setting overall values, including environmental, for the resource.

(ii) Sub-regional Allocation Plans- those which specify bulk water allocations.

(iii) Land Management Plans- Allocation and water-use management policies for the local resource. These are handled by specific licensing conditions.
The Environmental Water Provisions Policy of the Commission recommends the “Holistic Approach” (Arthington et al. 1992) as used as a model for provision for systems on the Swan Coastal Plain (see Davies et al. 1998). This approach was used in this present study.

**Holistic Approach**

A holistic approach (a building block procedure) was used for the assessment of the EWRs. This approach has been recommended as “best practice” to determine the EWRs of Australian systems (Arthington 1999). The holistic methodology is a sophisticated scientific approach that recognises the fundamental linkage between hydrology and ecology. In the holistic method, important water dependent components of ecosystems are initially defined in a value-identification process and then the amount of water required (spatially and temporally) to maintain these ecosystems at a low level of risk is determined.

This approach has been used elsewhere in river systems in Western Australia (e.g. North Dandalup River and the Harvey River) (Davies et al. 1998, Streamtec 1998, Welker & Davies 1998). This approach is fundamental in determining the “excess” capacity within a system after environmental concerns have been addressed through determination of the EWRs.

**Manning’s Equation**

Once the water-dependent components had been identified and field surveys completed, the actual water required for ecosystems was determined predominantly through the Manning’s Equation (Newbury & Gaboury 1993).

**Angove Creek Catchment**

**Water Supply**

Angove Creek is regulated by three pipehead dams, two of which form permanent pools (Clear Pool and Lower Pool). Water is abstracted from the creek for domestic and industrial supply to the town of Albany. Prior to 1981, mean abstraction rates were approximately 800 ML/annum and water was only abstracted from Clear Pool and mainly during summer. Following construction of a treatment plant, winter abstraction increased the total to about 1,100 ML/a. In 1998, WRC granted an interim allocation of 1,600 ML/a, pending a decision on a request by the Water Corporation (WC) for an increase in total allocation of between 1,800 ML/a increasing to 2,200 ML/a during wet years.

**Hydrology**

Baseflow within the lower Angove Creek is maintained by groundwater seepage with an estimated seasonal minima of approximately -50 kL/day per km of stream (L. Baddock, WC, pers. com.). However groundwater inputs appear highly seasonal and during drier periods, may be minimal. Long-term hydrological data on surface flows was available for WRC gauging station S602187, 1.8 km below Clear Pool. Complete records were only available for the period 1963 - 1981. Data indicated mean annual flow (MAF) in Angove Creek, below Clear Pool to be 1,854 ML with baseflow of about 1.8 ML/day (January - April). The different operating scenarios listed above, correspond to abstraction of about 30% MAF for rates of 800 ML/a, about 41% of MAF for 1,100 GL/a, 60% of MAF for 1,600 GL/a and 67 - 82% of MAF for the proposed 1,800 - 2,200 ML/a. The maximum proposed maximum abstraction of 2,200 ML/a would exceed the total flows for some drier years (e.g. 1969, 1974, 1975, 1976, and 1980). In this context, evaluation of EWRs is the scientific basis for determining ecologically sustainable rates of water abstraction.
Water Dependent Ecosystems

EWRs were determined for the Angove system from the forested, headwater regions upstream from Clear Pool (the water abstraction point) to reaches downstream from Angove Lake. Extensive field surveys were conducted in June 1999 at a range of sites and measurements made of water quality, channel morphology, fish biodiversity and riparian vegetation condition. The present study recorded four species of fish from the Angove system; Western Minnow (Galaxias occidentalis), Spotted Mountain Trout (Galaxias truttaceus), Swan River Goby (Pseudogobius olorum) and Swan River Hardyhead (Leptatherina wallacei). Given the timing and intensity of sampling, it is possible that other fish species occurred in the system but were not recorded. Although the focus of this report was the fish fauna, other important water dependent components of the riverine ecosystem were ascertained. Together these components comprised:

(i) riparian vegetation,
(ii) maintenance of Noisy Scrub Bird habitat, through preservation of existing riparian vegetation,
(iii) benthic macroinvertebrates,
(iv) fish passage and spawning,
(v) channel maintenance flows,
(vi) flows to maintain water levels in associated lakes (e.g. Angove Lake),
(vii) flows to control upstream saline water intrusion from the coast, and
(viii) water quality (e.g. in waters adjacent to agricultural lands).

The riparian zone of the majority of the Angove system classified as “near pristine” and, as such, was considered a critically important component of the landscape. High insect production in these areas supports much of the terrestrial fauna including the Noisy-scrub Bird.

Modified Flow Regimes

For each water-dependent component, spatial and temporal variation in water requirements were considered and the Manning’s Equation then used to calculate water volumes required to maintain specific stage heights. EWRs of Angove Creek were expressed as monthly “parcels” of water. A model was constructed based on the desired future state (DFS) of Angove Creek.

DFS: Current EWRs Met – Low Ecological Risk

The DFS was considered to be maintenance of existing ecological values, protected at a low level of risk. In this case, a baseflow of about 35 ML/month (~1.15 ML/day) (“delivered” at the old gauging station) was considered the minimum necessary for the maintenance of benthic invertebrates and native fish at downstream sites. As minimal transmission losses were apparent in Angove Creek, any EWR releases at the gauging station should be adequately transmitted down through the system. These monthly baseflows should also be sufficient to exceed the monthly evaporation rates of water from Angove Lake, though, it is likely that groundwater input will also contribute to lake water levels (L. Braddock, Water Corporation, pers. com.). A downstream culvert probably also controls water levels in the lake to a greater extent than input from the creek.

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1 Based on classification system of Pen & Scott (1995).
### Modelled Flow Regime:

**Flows to meet current EWRs of Angove Creek**

<table>
<thead>
<tr>
<th>Month</th>
<th>Baseflows</th>
<th>Fish passage</th>
<th>Channel maintenance</th>
<th>Lake water levels</th>
<th>Seasonal adjustment</th>
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</table>

**Total annual EWR = 882 ML** (increasing to 902 ML 1:3 years)

1. Baseflows are to maintain flow in riffles of at least 5cm in depth. This is to maintain benthic invertebrates (riffle zones are areas of high insect production) and ensure baseflow conditions for native fish.

2. Increased flows are required during August, September and October to enable the migration of native fish (i.e. these higher flows will "drown-out" many natural obstacles) and inundate streamside vegetation where some species attach eggs. Based on requirements of native fish where a minimum stage height of 35cm was considered necessary the migration.

3. The 155ML for August is to coincide with seasonally-elevated water levels to cause a flushing flow over an 18 hour period. These flows one year in three, outside this period, flows of 135 ML are required.

4. These flows are to maintain Angove Lake water levels. Although the lake is considered partly a function of groundwater, these flows are designed to exceed evaporation rates (by each month) within the lake.

5. Seasonal adjustments are to ensure EWRs reflect the historic flow regime.

In winter, flows of up to 135 ML/month (i.e. to reflect the historic flow regime) should be maintained, predominantly for fish migration and to allow some species to attach eggs to the inundated bank-side vegetation. The maintenance of a flushing flow of about 18 hours duration, approximately once every three years, is recommended to maintain the active channel and to flush accumulated detrital material from pools. This flushing flow need not require abstraction to cease during high rainfall events, as rates of abstraction (due to the current capacity of the water supply system) as a proportion of flood flows would be minimal and should be met by flood flows associated with elevated rainfall. Such flows will, in some reaches, inundate riparian zones stimulating seed-set and subsequent recruitment.

Vegetation of the riparian zone can either intercept groundwater or directly extract channel water. In many reaches of the Angove, which are bedrock controlled, much of the riparian vegetation would not have access to water in the channel and is probably maintained by interception of groundwater. Therefore in the EWR model, there is no specific surface water allocation for riparian vegetation, aside from the flushing flow.
Although outside the specific goal of EWR releases, in many regulated systems of the south-west, provision for EWRs can also ameliorate water quality problems which arise from poor catchment management. In the Angove system however, the biological water quality was high with nutrient levels well below statutory guidelines. Only slightly elevated total nitrogen concentrations were recorded in downstream reaches, probably as a consequence of uncontrolled livestock access to the channel.

Finally, seasonal adjustments to monthly flows ensured the natural seasonality of the Angove system was represented in the EWR model. The total EWRs of Angove Creek were determined to be about 882 ML in “normal” years, increasing to 902 ML one year in three when a flushing flow is required (see table overpage). Results from the current study indicated that the EWRs of reaches surveyed were being adequately met by existing flows.

**Water Abstraction**

Abstraction should *never* result in reaches of the river becoming dry. This would result in localised extinction of aquatic fauna, which due to the extent of obstructions, may be prevented from re-colonising impacted reaches. Therefore, abstraction must reflect as closely as possible the natural hydrology; *i.e.* higher rates in winter, reducing during summer. It should be noted that the hydrological record for Angove was collected during a “dry” climatic cycle. Overall patterns in annual rainfall show a slight decrease following the early 1950’s and a further decline since the early 1980’s. The re-commissioning of the existing gauging station on the Angove is recommended.

**Monitoring and Revision**

Comprehensive and scientifically competent in-stream flow recommendations can only be made where there is fundamental knowledge of the river and associated ecological systems. It must be emphasised that EWRs recommended for the Angove system are essentially a “best scientific guess”. The EWRs have been formulated in the context of an incomplete ecological record (one field trip only) and limited hydrological data (1963 to 1982). The field component of the Angove Creek study was essentially a “snap-shot” conducted during moderate flows. Generally, similar fieldwork during late summer would be required to assess the system at a time of increased ecological stress due to seasonally-low water-levels. Provision should therefore be made within the budget of water resource projects for these initial estimates to be refined and adjusted over time as the effects of the initial recommendations are monitored (Arthington *et al.* 1992). Therefore it is critical that the proposed abstraction be considered in an adaptive management context (*e.g.* Adaptive Environmental Assessment and Management: AEAM). In adaptive management, the ecological consequences of the proposed increased abstraction should be carefully monitored.

**Recommendation for Monitoring and Management Issues for Angove Creek**

Ideally, monitoring the impacts of increased abstraction should include:

1. Measurements of physical parameters, *i.e.* pool aggradation, channel stability, water levels in Angove Lake;
2. Biological parameters, including fish recruitment and macroinvertebrate community structure;
3. Water quality parameters, including nutrient status of the Angove Lake and the extent of saline intrusions in reaches downstream from the lake. A culvert in the reach immediately downstream of the lake regulates the extent of an upstream “wedge” of saline water from the coast. The responsibility of this culvert needs to be determined through consultation with the landholder, Department of CALM, WC and the WRC.
4. Riparian vegetation, particularly in reaches where the banks are steep to provide an "early warning" of impacts of changes in flow. Fixed photographic points would aid in assessment of some of these parameters, e.g. channel stability (bank slumping, undercutting) and changes in riparian vegetation structure and density. The final monitoring design will necessarily be a function of funding-support.

Limeburners Creek Catchment

Limeburners Creek is a small, forested first-order creek southwest of Albany. The creek has a small, ill-defined estuary in Shool Bay. A pipehead dam was built on the creek approximately 40 years ago to augment groundwater supplies from the South Coastal borefield to the town of Albany. However, due to water quality problems, this source was not used between 1992 and 1998. In December 1998, the Water Corporation re-commissioned this source with the installation of an additional, temporary-treatment plant.

Limeburners Creek is characterised by pristine riparian vegetation (A1 - A2) and, due to catchment size, low flow rates. Available flow records (station 602041, 1954-1963) showed the creek to be perennial with a MAF of about 500 ML. The lack of seasonality (e.g. coefficient of variation of monthly flows of 17%) indicated the overriding influence of groundwater in maintaining water levels in the creek.

Sampling revealed a system reasonably depauperate of aquatic fauna. During June 1999, no fish were collected and the biodiversity of macroinvertebrate fauna was extremely low, possibly due to the small size of the creek and the lack of habitat diversity. Therefore, important water-dependent components of these ecosystems were limited. The desired future state (DFS) for the creek was considered to one that protected current condition / values at a low level of ecological risk. In this context, the only EWR was considered to be the provision of flow to ensure the creek remains perennial. Due to the lack of seasonality of flows, abstraction from the creek could be constant throughout the year. Due to the lack of important water dependent ecosystems in Limeburners Creek, monitoring the impact of abstraction is not considered necessary. These types of first and second-order creeks are well represented elsewhere on the south-coast of Western Australia.

Concluding Remarks

The EWRs determined in this report represent an initial "request" for water to the environment. The final allocation (the EWP) is determined after social, economic and industrial users have also been considered. EWPs were beyond the scope of this present study. The recommended flow regimes are designed to maintain the existing aquatic ecosystems with continued low ecological risk.
1. INTRODUCTION

1.1 Angove Creek

Angove Creek is a major catchment of the ecologically-important Two Peoples Bay Reserve. The Reserve has been recognised as valuable aquatic habitat of both streams and lakes (e.g. Gardner, Moates and Angove). The riparian vegetation supports rare and threatened species including the Noisy Scrub Bird (Atrichornis clamosus) and the Australasian Bittern (Botaurus poiciloptilus) and has the potential to provide habitat for the extremely rare Gilbert's Potoroo (Potorous tridactylus gilberti) (A. Danks, CALM Albany, pers. comm. 1999). The upper Angove catchment is relatively pristine with only about 5% cleared.

Angove Creek is regulated by a pipehead dam constructed in 1912-1913 to supply domestic and industrial water to the town of Albany. Construction of the dam resulted in the formation of Clear Pool. Water was originally abstracted, mainly over summer, as during winter the water was considered too highly coloured for domestic supply. In 1981, a treatment plant was installed to overcome this problem. Prior to 1981, abstraction rates varied from 500 – 1,000 ML/year, however with the construction of the treatment plant, winter abstraction increased these rates to 1,100 ML/year. In total there are now three weirs on the Angove Creek, two of which, Clear Pool and Lower Pool, form permanent pools.

1.2 Limeburners Creek

The pipehead dam at Limeburners Creek was built approximately 40 years ago to augment groundwater supplies from the South Coastal borefield to the town of Albany. However, due to water quality problems, this source was not used between 1992 and 1998.

In December 1998, the Water Corporation recommissioned this source with the installation of an additional temporary treatment plant at the South Coastal treatment plant.

1.3 Water Abstraction

Currently, the Water Corporation abstracts water from Clear Pool under a Water & Rivers Commission (WRC) interim licence that allows up to 1,600 ML/a in total to be extracted from the Two Peoples Bay area. Approximately 100 ML/year is pumped from Limeburners Creek under a licence allocation of up to 200 ML/a. However, due to increasing demand, the Water Corporation has requested the allocation from Angove be increased to 1,800 ML/a and up to 2,200 ML/a during wet years. Abstraction from Limeburners Creek would also be increased to 300 ML/a. This additional water would be abstracted over winter.

1.3.1 Approval Process

Approval by the WRC for increased water allocations is subject to an environmental impact assessment (EIA) of the effects of increased abstraction on the downstream ecosystems. In 1998, the Water Corporation received an interim allocation of 1,600 ML/year from Clear Pool until the EIA is complete. This interim allocation is also subject to a minimum environmental water release downstream from Lower Pool.

1.3.2 Statutory Framework

Environmental Water Requirements (EWRs) are critical for the maintenance of riverine ecosystems downstream from impoundments (see Davies et al. 1998). EWRs are based on the premise that the environment has a right to water; that is it has to be regarded as a legitimate user.
The terminology used in this report is based on that used in the *National Principles for the Provision of Water for Ecosystems* (ARMCANZ/ANZECC, 1996) where:

- **Environmental Water Requirements** (EWRs) describe water regimes (spatial and temporal) needed to sustain the ecological values of water dependent ecosystems at a low level of risk.

- **Environmental Water Provisions** (EWP) are that part of the environmental water requirements that can actually be met after consideration of social and economic factors.

EWRs that maintain the ecological integrity of river systems, are also consistent with the objectives of the Environmental Protection Authority of Western Australia (EPA) to “maintain or improve the quality of surface water to ensure that existing and potential uses, including ecosystem maintenance are protected” (EPA 1993). Both State and Federal Governments have endorsed the National Strategy for Conservation of Australia's Biological Diversity and the National Strategy for Ecologically Sustainable Development which are designed to “protect biological diversity and maintain essential ecological processes and life support systems”.

In Western Australia, the Water and Rivers Commission (WRC) uses a “Draft Environmental Water Provisions Policy” as a context for water allocation. In the formulation of this policy, the Commission was guided by the “National Principles for the Provision of Water for Ecosystems” (ARMCANZ/ANZECC 1996). At present, there are three nominal levels of Allocation Plans forming the basis of decisions on water allocations:

(i) Regional Allocation Plans— those that guide overall management of water resources for a region by setting overall values, including environmental, for the resource.

(ii) Sub-regional Allocation Plans— those which specify bulk water allocations.

(iii) Land Management Plans— Allocation and water-use management policies for the local resource. These are handled by specific licensing conditions.

In order to minimise the environmental impact of altering the river flow, it is necessary to consider the environmental water requirements (EWRs) of the river environment, compare this to the actual flows and ecosystem response, and adjust management practices accordingly. The Environmental Water Provisions Policy of the Commission recommends the “Holistic Approach” (Arthington et al. 1992) as used as a model for provision for systems on the Swan Coastal Plain (see Davies et al. 1998). This approach was used in this present study.

**1.4 Specific Aims & Scope of the Report**

The current study was commissioned by the Water Corporation to assess the impact of proposed increases in abstraction on the aquatic ecology of Angove and Limeburners creeks. Assessments for the determination of environmental EWRs used the “holistic approach” for in-stream flow assessments. Further details of the procedure may be found in Davies et al. (1998).

One of the main principals of this approach is that the modified flow regime should represent (as closely as possible) the natural flow regime.
This approach was initially proposed partly to overcome the limitations of existing in-stream flow methods, and to redirect the emphasis of in-stream flow management away from species assessments towards the ecosystem level and maintenance of flow-dependent ecosystem processes (Arthington et al. 1993, Davies et al. 1998).

Specific aims of the current study were as follows:

(i) Determine the environmental water requirements (EWRs) for the Angove Creek system (downstream from Clear Pool) and for Limeburners Creek;

(ii) Assess proposed increases in water abstraction in view of the above EWRs;

(iii) Develop appropriate monitoring strategies for the dependent riverine and lake ecosystems in the context of increased water abstraction.

Methods employed to meet these aims included:

- *Analysis of historical data* on hydrology to identify likely impact of altered water regimes;

- *A survey of existing channel morphology and flow regimes* to determine flows to maintain channel and associated river pools and wetlands (water levels in pools are important to maintain ecological processes and fringing vegetation);

- *A survey of fish fauna.* Key flow requirements of native fish, known to be present, were considered to ensure that EWRs were sufficient to (a) generate high flow conditions for species that spawn in flooded riparian vegetation and (b) to enable movement of adults and juveniles;

- *A survey of riparian vegetation.* Flows into riparian zones are important to stimulate seed set and for subsequent recruitment of river-bank vegetation;

- *A literature survey* of research conducted on the flora and fauna associated with the two systems.
2. ANGOVE CREEK CATCHMENT

2.1 Study Area
The Angove Creek catchment is located in the Two Peoples Bay area, approximately 40 km east of Albany. The catchment is within the Albany Coast Drainage Basin in the South West Drainage Division of Western Australia. Angove Creek dissect the sediments of the Pallinup Siltstone that comprise fine-grained sandstone and siltstone overlying granitic rocks outcropping as hills and within parts of the creek (I. Baddock, Water Corporation, pers. comm.). A narrow coastal plain with dunal sands and possibly sub-surface limestone lies between the coast and an escarpment. Angove Creek flows to the shallow coastal swamplands of Angove Lake, and from there, through a constructed drain, it joins the Goodga system at Gardner Creek on the seaward side of Gardner Lake. Angove and Gardner lakes are situated on the inland margin of the coastal plain (I. Baddock, Water Corporation, pers. comm.).

About 5% of the catchment has been cleared for pasture, predominantly in the headwater region and the lands surrounding Angove Lake.

Angove Lake has an area of 50ha, which together with surrounding swamps and inundated lands comprise a total wetland area of 120ha. Part of these wetlands and a stretch of river immediately upstream, are included in the Two Peoples Bay Nature Reserve - an “A” Class Nature Reserve for the Conservation of Fauna (A27956), initially established to protect the Noisy Scrub-bird (*Atrichornis clamosus*) and its habitat. The Department of Conservation and Land Management (CALM) are responsible for management of the reserve.

*Agonis juniperina* low forest, scrub and thickets surrounding drainage lines and lakes are important habitat for the Noisy Scrub-bird (CALM 1995).

The Angove system is also an important conservation area for other species, for example, freshwater fish, the Australasian Bittern (*Botaurus poiciloptilus*) and Gilbert’s Potoroo (*Potorous tridactylus gilberti*). The Bittern is known to inhabit *Baumea articulata* sedgelands such as those fringing Angove Lake (Pen 1998). Gilbert’s Potoroo is an extremely rare marsupial on the brink of extinction (until its re-discovery in the Mt Gardner area in 1994 it was presumed extinct) (CALM 1995). Historically, Gilbert’s Potoroo was typically found in swamplands and dense heath associated with gullies and drainage lines (A. Danks, CALM Albany, pers. comm. 1999). With continued protection of this species, there is the potential that similar riparian vegetation zones in the Angove catchment will provide habitat.

2.2 Study Sites

The location of the study area and the Angove Creek study sites is indicated in Figure 1. Seven sites were sampled between 3 - 4 June 1999.

The habitat typical of these sites is depicted in Plates 1 - 6 and the cover photograph. The latitude and longitude of each site is also given in Table 1. Opportunistic observations were also made at various points between study sites in Angove Creek.
Figure 1. Location of study area and study sites in Angove Creek, June 1999.
Plate 1 (top left). Site 2 Angove Creek, immediately downstream from Clear Pool. Much of the channel bed-rock controlled.
Plate 2 (bottom). Site 3 Angove Creek, gauging station adjacent to Pump Station.
Plate 3. (top right). Site 4 Angove Creek, on northern boundary of private farmlands, ~7 km upstream from Angove Lake. Narrow channel with steep banks.
Plate 4 (top). Angove Drain, immediately downstream from Site 6, at road culvert.
Plate 5 (bottom). Site 7, mouth of Gardner Creek (looking upstream) at Two Peoples Bay, ~8 km downstream of the confluence with Angove Drain.
2.3 Determining the Hydrological State of the Catchment

The first stage of assessing adequate EWRs for a river system is to determine the existing hydrological state of the catchment. This is critical, as typically the further a river system is removed from its historic hydrology, the more the environment, and therefore, ecological values are impacted.

Angove Creek is relatively short, 14 km, with a catchment area of approximately 42 km², much of which lies within Water Supply Reserve 13802. Baseflow within Angove Creek is maintained by groundwater seepage predominantly from the Pallinup Siltsite sediments (L. Baddock, Water Corporation, and pers. comm.). Seepage is estimated to be approximately 50 kL/day per km of stream length, based on observed streamflow in April 1999. Sampling during other occasions (June 1998 and April 2001) showed groundwater inputs to be minimal. Therefore groundwater contributions are expected to be highly seasonal. However, Angove Lake is expected to receive groundwater discharge from an area of approximately 6 km² west of the lake. A portion of discharge from the lake is likely to occur as seepage to Two Peoples Bay through the intervening dune ridge approximately 400 m wide (L. Baddock, Water Corporation, pers. comm.).

Data from WRC gauging station S602187, at the Pump Station (immediately below Clear Pool) on Angove Creek, was used for assessment of post-impoundment flows. This station records overflow from Clear Pool. A complete monthly data record was only available for the period 1963 – 1981 and for January – October 1999.

For the period 1963 - 1981, the MAF was 1,854 ML (median 1,600 ML/annum) (Figure 2), with a minimum of 998 ML during drier years, such as 1981 (PWD 1984). Average summer flows (i.e. baseflows, January - April) ranged from 1.14 – 2.36 ML/day (mean ~1.8 ML/day). More recent data from 1999 indicated mean baseflows downstream of Clear Pool, to be 1.2 - 1.58 ML/day (median 1.17 – 1.42 ML/day) (Figure 3). Table 2 shows the different operating scenarios corresponding to three different rates of abstraction between 1963 – 1998 and one proposed rate for future abstraction. These different rates corresponded to abstraction of about 30% of mean annual flows (MAF) for rates of 800 ML/a, about 41% of MAF for 1,100 ML/a, 60% of MAF for 1,600 ML/a and 67 - 82% of MAF for the proposed 1,800 - 2,200 ML/a.

2.3.1 Determining Predictability & Seasonality of Stream Flow

The pre-impoundment flow regime for the Angove Creek was estimated based on rainfall data (from the Kalgan and Many Peaks rainfall gauging stations), supplied by Climate Services, Bureau of Meteorology (Figures 4 - 7). Monthly rainfall data revealed that current streamflow resembles pre-impoundment flows in so far as being predictable and highly seasonal with maximum flows occurring in June – July (Figures 2 - 4). Highest pre-impoundment flows would also typically have occurred during June - July.

The historic rainfall record was further analysed using a measure of time series (Colwell’s Indices). This index is particularly useful for describing temporal patterns in flow data and partitions the overall Predictability (P) into the degree of Constancy (C) and Contingency (M). The latter is a measure of the seasonality of the pattern. Values of P range from 0 (unpredictable) to 1 (totally predictable). Predictability (P) of 1 would occur only if flows in every month were the same every year of the total records.
### Table 1. Latitudes and longitudes of sites surveyed in Angove Creek, Two Peoples Bay region, June 1999.

<table>
<thead>
<tr>
<th>Site code</th>
<th>Site name</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Clear Pool</td>
<td>34°54'35&quot;S</td>
<td>118°08'36&quot;E</td>
</tr>
<tr>
<td>2</td>
<td>Below Clear Pool</td>
<td>34°54'50&quot;S</td>
<td>118°08'36&quot;E</td>
</tr>
<tr>
<td>3</td>
<td>Pump Station</td>
<td>34°55'28&quot;S</td>
<td>118°08'56&quot;E</td>
</tr>
<tr>
<td>4</td>
<td>Upstream Angove Lake</td>
<td>34°55'51&quot;S</td>
<td>118°09'07&quot;E</td>
</tr>
<tr>
<td>5</td>
<td>Angove Lake</td>
<td>34°56'42&quot;S</td>
<td>118°09'25&quot;E</td>
</tr>
<tr>
<td>6</td>
<td>Angove Drain</td>
<td>34°57'12&quot;S</td>
<td>118°09'35&quot;E</td>
</tr>
<tr>
<td>7</td>
<td>Estuary</td>
<td>34°58'24&quot;S</td>
<td>118°08'56&quot;E</td>
</tr>
</tbody>
</table>

### Table 2. Analysis of the flow record from Angove Pump Station (1963-1981). Total annual flow (ML) was calculated by adding the annual flow (1963 – 1981) to the annual pumpage for each year. The different operating scenarios correspond to the three different abstraction rates (1963 scenario = -800 ML/a, 1978 = 1,100 ML/a, 1998 = 1,600 ML/a and proposed = 1,800 - 2,200 ML/a).

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Annual Flow (ML/a)</th>
<th>1963 Scenario (% diverted)</th>
<th>1978 Scenario (% diverted)</th>
<th>1988 Scenario (% diverted)</th>
<th>Proposed 1,800 - 2,200 ML/a (% diverted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1963</td>
<td>2.42</td>
<td>33.06</td>
<td>45.45</td>
<td>66.12</td>
<td>74.38</td>
</tr>
<tr>
<td>1964</td>
<td>2.52</td>
<td>31.75</td>
<td>43.65</td>
<td>63.49</td>
<td>71.43</td>
</tr>
<tr>
<td>1965</td>
<td>2.27</td>
<td>35.24</td>
<td>48.46</td>
<td>70.48</td>
<td>79.30</td>
</tr>
<tr>
<td>1966</td>
<td>2.35</td>
<td>34.04</td>
<td>46.81</td>
<td>68.09</td>
<td>76.60</td>
</tr>
<tr>
<td>1967</td>
<td>3.10</td>
<td>25.81</td>
<td>35.48</td>
<td>51.61</td>
<td>58.06</td>
</tr>
<tr>
<td>1968</td>
<td>3.38</td>
<td>23.67</td>
<td>32.54</td>
<td>47.34</td>
<td>53.25</td>
</tr>
<tr>
<td>1969</td>
<td>1.97</td>
<td>40.61</td>
<td>55.84</td>
<td>81.22</td>
<td>91.37</td>
</tr>
<tr>
<td>1970</td>
<td>2.25</td>
<td>35.56</td>
<td>48.69</td>
<td>71.11</td>
<td>80.00</td>
</tr>
<tr>
<td>1971</td>
<td>3.45</td>
<td>23.19</td>
<td>31.88</td>
<td>46.38</td>
<td>52.17</td>
</tr>
<tr>
<td>1972</td>
<td>2.32</td>
<td>34.48</td>
<td>47.41</td>
<td>66.97</td>
<td>77.59</td>
</tr>
<tr>
<td>1973</td>
<td>2.43</td>
<td>32.62</td>
<td>45.27</td>
<td>65.84</td>
<td>74.07</td>
</tr>
<tr>
<td>1974</td>
<td>1.87</td>
<td>42.78</td>
<td>58.82</td>
<td>85.56</td>
<td>96.26</td>
</tr>
<tr>
<td>1975</td>
<td>2.06</td>
<td>38.46</td>
<td>52.98</td>
<td>76.92</td>
<td>86.54</td>
</tr>
<tr>
<td>1976</td>
<td>2.16</td>
<td>37.04</td>
<td>50.93</td>
<td>74.07</td>
<td>83.33</td>
</tr>
<tr>
<td>1977</td>
<td>3.51</td>
<td>22.79</td>
<td>31.34</td>
<td>45.58</td>
<td>51.28</td>
</tr>
<tr>
<td>1978</td>
<td>4.18</td>
<td>19.14</td>
<td>26.32</td>
<td>38.28</td>
<td>43.06</td>
</tr>
<tr>
<td>1979</td>
<td>4.19</td>
<td>19.09</td>
<td>26.25</td>
<td>38.19</td>
<td>42.96</td>
</tr>
<tr>
<td>1980</td>
<td>2.08</td>
<td>38.46</td>
<td>52.98</td>
<td>76.92</td>
<td>86.54</td>
</tr>
<tr>
<td>1981</td>
<td>2.40</td>
<td>33.33</td>
<td>45.83</td>
<td>66.67</td>
<td>75.00</td>
</tr>
</tbody>
</table>
A Constancy (C) of 1 would only occur if monthly flows were totally predictable as above and also if they were the same across all months.

A Contingency (M) of 1 would only occur if monthly flows were totally predictable as above and if they were different in every month. Patterns of discharge can thus be described not only in terms of the overall predictability but also the degree of seasonality.

Absolute values of Colwell's index are strongly influenced by the number of categories (in this case, categories of monthly flows) and, in the case of small data sets, the number of years of data (see Gan et al. 1991). Comparisons among data sets are only valid if the same number of years of data (in the case of small data sets) and the number of categories are constant. As a consequence, many researchers use a standardised number of categories of monthly flows to enable comparisons of rivers of varying size and discharge across Australia. Analyses showed the "natural" (unregulated) flows for Angove Creek would have been highly predictable with low constancy and high seasonality corresponding to rainfall (Table 3). This seasonality is manifest in a system characterised by drier summer/autumn periods. There would have been no periods of zero-flow based on the historic rainfall records. The fact that flows never ceased is an important and highly predictable feature of the flow regime that should be maintained.

The past 20 year's rainfall in south-western Australia have been below average (WRC 1997). Climate change predictions (for the year 2030) for the south-west, due to global warming, are a temperature increase of between 0.3 and 1.3°C. Rainfall and streamflow are predicted to increase during summer and reduce during winter/spring (CSIRO 1996).

Overall patterns in annual rainfall for the Angove region show a slight decrease following the early 1950's and a further decline since the early 1980's (Figure 7).

Table 3. Predictability (P), Constancy (C) and Contingency (M) (after Colwell 1974), of 19 years of total monthly flows (based on rainfall data), and maximum and minimum instantaneous flows.

<table>
<thead>
<tr>
<th></th>
<th>P</th>
<th>C</th>
<th>M</th>
<th>M/IP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total monthly flow</td>
<td>0.62</td>
<td>0.30</td>
<td>0.28</td>
<td>47</td>
</tr>
<tr>
<td>Rainfall</td>
<td>0.69</td>
<td>0.26</td>
<td>0.30</td>
<td>43</td>
</tr>
</tbody>
</table>

2.3.2 Determining Creek Morphology & Active Flows for Stream Channel Maintenance

To determine channel maintenance flows, extensive measurements were made of river channels in June 1999. Detailed measurements of hydraulic geometry were made using a surveyors' dumpy level and a staff. Measurements included reach slope, mean bankfull width and depth, and the bed materials. The cross-sectional shape (profile) of the stream at each site was recorded at 25, 50 and 75 meters progressing upstream from the downstream end of each 100m reach. This included measuring width and depth and estimating bankfull level. The wetted-width of the stream was measured at up to three locations (according to accessibility) in each third (upper, mid and lower) of the reach. These data were then expressed as the mean width for the reach.

The active channel width and depth were determined as per the methodology outlined in Newbury and Gaboury (1994). The following parameters were used:

\[ n = 0.04 \times d_{50}^{1/6} \]

where \( d_{50} \) = median bed particle size = 0.016 at active channel stage.
Average velocity was estimated as the velocity at 0.4 times the maximum depth of the stream (Newbury and Gaboury 1993). To measure discharge, a narrow segment of stream of uniform shape was selected and velocity measured using a field velocity meter (Marsh McBurney Model 201M). Discharge volume \((Q)\) was calculated using the relationship:

\[
Q = \text{width} \times \text{depth} \times \text{average velocity}
\]

Active channel flows were calculated using Manning’s Equation:

\[
Q_{cb} = C \frac{D^{2/3}}{S^{1/2}} \frac{W^{2/3}}{n}
\]

where \(D\) = mean depth, \(W\) = mean width, \(S\) = slope of the active channel, \(n\) = Manning’s \(n\) at bankfull (active channel) stage (Newbury & Gaboury 1993).

It is the dominant discharge (i.e. \(Q_1\) or \(Q_{1.5}\)) that is most important in maintaining an active channel, free from accumulated silt and debris. Flows of this magnitude and return frequency also create and maintain the characteristic geometry of the stream channel (Newbury & Gaboury 1994).

The analysis of the hydraulic geometry of the catchment established the significant relationships between active channel width and drainage area, and channel depth and drainage area. The coefficients of variation of monthly flows was then used to estimate the desired magnitude of flow variation that would permit flushing flows and maintain the distinctive features of the winter flows downstream.

Discharge rates at the time of sampling are shown in Table 4. There was little variation between sites with rates ranging from 0.059 \(\text{m}^3/\text{sec}\) upstream of Angove Lake (Site 4) to 0.0695 \(\text{m}^3/\text{sec}\) coming over the weir at Clear Pool (Site 1). This indicated little or no gains from groundwater or tributaries. Thus, net transmission gains or losses between Clear Pool and Angove Drain (Site 6, \(Q = 0.0652 \text{m}^3/\text{sec}\)) were considered to be negligible.

At each site, bankfull discharges (\(Q_{cb}\)) were estimated as the (Table 4). Flows ranged from 78.21 \(\text{m}^3/\text{sec}\) at the pump station (Site 3) to 115.69 \(\text{m}^3/\text{sec}\) at Angove Drain (Site 6).

<table>
<thead>
<tr>
<th>Site code</th>
<th>(Q_{sampling}) (\text{m}^3/\text{sec})</th>
<th>(Q_{cb}) (\text{m}^3/\text{sec})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0695</td>
<td>86.69</td>
</tr>
<tr>
<td>2</td>
<td>0.0891</td>
<td>90.30</td>
</tr>
<tr>
<td>3</td>
<td>0.0882</td>
<td>78.21</td>
</tr>
<tr>
<td>4</td>
<td>0.0660</td>
<td>88.45</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>0.0652</td>
<td>115.69</td>
</tr>
<tr>
<td>7</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Bankfull discharges are typically used as representative of channel maintenance flows. However, given the historic flow regime it is unlikely that flows of this volume would have been a frequent occurrence. Instead, a flushing flow of approximately 155 ML for 18 hours duration, once every three years, would maintain the active channel and flush accumulated debris. This volume was calculated using the estimates of \(Q_{cb}\) by measurements of channel morphology as input to the Manning’s Equation.

<table>
<thead>
<tr>
<th>EWRS FOR ACTIVE FLOWS FOR STREAM CHANNEL MAINTENANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
</tr>
<tr>
<td>155 ML</td>
</tr>
</tbody>
</table>
Figure 2. Post-impoundment (January 1963 to December 1982) monthly flows at WRC gauging station S602187, immediately downstream of Clear Pool, Angove Creek.

Figure 3. Flow (ML) in Angove Creek during 1999 together with total monthly rainfall (Kalgar Strn 9559). Abstract = total abstraction from Clear Pool (thousands of ML/month); ML/day = total daily flows recorded below Clear Pool (S602187) including baseflow; "Base Flow" = baseflow only.

Figure 4. Post-impoundment (January 1963 to December 1982) flow (ML) duration analysis for WRC gauging station S602187, 1.8 km downstream of Clear Pool, Angove Creek. (Flow categories: 0 to 0.1 ML, 0.1+ to 0.3 ML etc.)
Figure 5. Median monthly rainfall (mm) at the Kalgan station (9559) (1963 – 1982), together with median and mean monthly stream discharge recorded in Angove Creek, S602187 (1963 – 1982).
Rainfall data courtesy of J. Relf, Climate Services, Bureau of Meteorology.

Figure 6. Median rainfall (Kalgan 9559) for the same period (1963 – 1982) as long-term stream discharge records (S602187) compared to the longer-term median (1911 – 2000).
Data courtesy of J. Relf, Climate Services, Bureau of Meteorology.

Figure 7. Long-term total annual rainfall (mm) recorded within the region of Angove Creek catchment, at Kalgan (9559) (1911 – 1998) and Many Peaks (9582) (1931 – 1988).
Data courtesy of J. Relf, Climate Services, Bureau of Meteorology.
Figure 7. CALM monitoring data on Angove Lake water depth together with total monthly rainfall (Keigan station 9559).

Figure 8. CALM monitoring data on Angove Lake water depth and salinity levels.
2.3.3 Determining EWRs of Angove Lake

Angove Lake is the consequence of both surface and groundwater inputs and historically, during extreme tidal conditions, probably received saline water from the estuary. At present, a culvert downstream from the lake controls the upstream extent of a salt-water wedge. Increased salinity as a result of either reduced freshwater input from Angove Creek or the removal of the culvert may have a dramatic impact on the surrounding *Baumea* sedges of the lake and associated aquatic fauna. This sedge has a maximum salinity tolerance of about 2 – 3 ppt and is important as habitat for waterfowl.

Water depth and salinity levels in Angove Lake have been monitored by CALM every two months between November 1981 and May 1985, and on isolated occasions during 1979, 1980 and 1990. The data showed a distinct seasonal pattern in water level that was correlated with local rainfall (Figure 8, Appendix Table A1). Salinity was inversely correlated with water level (Figure 9). Although abstraction from Angove Creek increased between 1980 and 1990, no prior depth data were available, thus no conclusions could be made as to the overall impact on lake water levels.

In the absence of a detailed hydro-geological survey (such a survey was beyond the scope of the current study), contributions from groundwater could not be factored into EWR estimates. Thus to ensure water provision to maintain water levels in Angove Lake, EWRs were calculated assuming lake levels were solely a function of creek discharge.

No concurrent discharge data were available to ascertain the relationship between streamflow and lake water levels.

Monthly flows required to exceed the monthly evaporation rates of water from the lake were therefore calculated using a mean evaporation rate of 1470 mm/annum (PWD 1984). Estimates of area and water volume of the lake were based on CALM (1995) data, while water depth was measured on-site. From these parameters it was estimated that 6 ML/month in winter and up to 35 ML/month in summer is required to maintain water levels:

<table>
<thead>
<tr>
<th>EWRs to Maintain Angove Lake</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (ML)</td>
<td>Month</td>
</tr>
<tr>
<td>35</td>
<td>January</td>
</tr>
<tr>
<td>29</td>
<td>February</td>
</tr>
<tr>
<td>26</td>
<td>March</td>
</tr>
<tr>
<td>14</td>
<td>April</td>
</tr>
<tr>
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<td>May</td>
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<td>June</td>
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</tr>
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<td>October</td>
</tr>
<tr>
<td>34</td>
<td>November</td>
</tr>
<tr>
<td>35</td>
<td>December</td>
</tr>
</tbody>
</table>

2.4 Aquatic Invertebrate Fauna

No detailed survey of macroinvertebrates was conducted during the current study. However, a water depth of 5 cm over riffle zones is considered the minimum necessary to support benthic invertebrate communities in other similar riverine systems in the south-west (Davies unpubl. data). Riffle zones are typically areas of high insect production (Davies 1993).

The Manning's Equation was used to calculate what water volumes would be required to maintain this stage height. Analysis of the historic flow record showed the Angove to be a perennial system, therefore this minimum 5cm depth is needed every month. An estimated baseflow of approximately 35 ML/month would be required to provide this depth of water in Angove Creek:
2.5 Fish Fauna

Fish were sampled by a combination of methods including electrofishing, sweep nets (in areas of reed beds, bank undercuts and under logs), seine nets across the channel or by direct observation. All specimens collected were identified to species, before being returned live to the water.

2.5.1 Distribution of Freshwater Fish Species in the Southwest

The fish fauna of the Angove Creek (and adjoining Goodga River) has not been extensively studied, with no published studies, although the Western Australian Museum holds collections from this system by L. Glaubert in 1941, GR Allen in 1976, 1980 and 1986, NJ Cross in 1981 and NJ Coy in 1990 (Neil Coy, unpub. data.) and Morgan et al. (1996). The present study recorded four species of fish from the Angove system; Spotted Mountain Trout, Swan River Goby, Swan River Hardyhead and probably the Common Jollytail (Table 5).

A total of seven sites were sampled on the Angove system (e.g. four sites above Angove Lake, one site in the lake, and two sites between the lake and the sea). Sites were sampled on one occasion in early winter. Given the timing and intensity of sampling, it is possible that other fish species occur in the system but were not sampled on this occasion. The literature (Allen, 1989; Morgan et al. 1996, Coy, unpub. data) indicates that the Angove system lies within the known distributions of eight species of freshwater fish (Tables 5 & 6). The eastern limit of two of these species is in this vicinity; Balston’s Pygmy Perch limited to Two Peoples Bay, and the Western Minnow extending to Waychinicup Creek. The area also holds two species which have very restricted distributions in southwestern Australia, occurring in several rivers immediately to the east of Albany (e.g. Spotted Mountain Trout) or in coastal streams between Albany and Esperance (e.g. Common Jollytail).

Two other freshwater fish common throughout southwestern Australia, Nightfish (Bostockia porosa) and Freshwater Cobbler (Tananaus bostocki) have never been recorded as far east as Albany and so were unlikely to be recorded in this study. Similarly, the less common endemics, Salamanderfish (Lepidotigalaxias salamandroides), Black-Stripe Minnow (Galaxiella nigrostriata) and Mud Minnow (Galaxiella mundula), which generally are restricted to the southwestern corner of Western Australia.

Of the four additional species expected but not recorded in this study (e.g. Western Minnow, Western Pygmy Perch, Balston’s Pygmy Perch, Big Headed Goby), Balston’s Pygmy Perch is relatively rare, and generally occurs in low abundance in systems where it is present. It therefore may be in the system, but were not sampled.

The Western Pygmy Perch is usually very common and easy to catch in systems where it is present. The absence of this species in samples probably indicates it is not present in the Angove system, however, Coy (unpub. data) recorded this species from the Angove system in 1990.
Table 5. Summary of fish species recorded and expected in the Angove system, compared to known distributions in southwestern Australia (Allen, 1989; Morgan et al. 1996, Coy, unpub. data).

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific name</th>
<th>Likely to occur in the Angove system</th>
<th>Recorded in this study</th>
<th>Reaches in which likely to occur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western Minnow</td>
<td>Galaxias occidentalis</td>
<td>✓</td>
<td>✓</td>
<td>2, 3, 4</td>
</tr>
<tr>
<td>Spotted Mountain Trout</td>
<td>Galaxias truttaceus</td>
<td>✓</td>
<td>✓</td>
<td>2, 3, 4</td>
</tr>
<tr>
<td>Common Jolitail</td>
<td>Galaxias maculatus</td>
<td>✓</td>
<td>✓</td>
<td>2, 3, 4</td>
</tr>
<tr>
<td>Western Pygmy Perch</td>
<td>Edelia vittata</td>
<td>✓</td>
<td>✓</td>
<td>2, 3, 4</td>
</tr>
<tr>
<td>Balston’s Pygmy Perch</td>
<td>Nannatherina balstoni</td>
<td>✓</td>
<td>✓</td>
<td>2, 3, 4</td>
</tr>
<tr>
<td>Swan River Goby</td>
<td>Pseudogobius olorum</td>
<td>✓</td>
<td>✓</td>
<td>3, 4</td>
</tr>
<tr>
<td>Big Headed Goby</td>
<td>Afurcagobius suppositus</td>
<td>✓</td>
<td>✓</td>
<td>3, 4</td>
</tr>
<tr>
<td>Swan River Hardyhead</td>
<td>Leptatherina wallacei</td>
<td>✓</td>
<td>✓</td>
<td>4</td>
</tr>
<tr>
<td>Freshwater Cobbler</td>
<td>Tandanus bostocki</td>
<td>❌</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Nightfish</td>
<td>Bostockia porosa</td>
<td>❌</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

(1 = upper reaches above natural waterfalls, 2 = mid reaches above Angove Lake and below the waterfalls, 3 = Angove Lake, 4 = drain and lower river between Angove Lake and the outlet to the sea at Two Peoples Bay).

Table 6. Summary of known distributions of freshwater fish in southwestern Australia (cf. Table 5).

Common throughout southwestern Australia
- Western Minnow – coastal drainages between Waychinicup Creek (80 km east of Albany) and Winchester (250 km north of Perth).
- Western Pygmy Perch – southwestern Australia between Hopetoun (Philipps River) and the Moore River, in lakes, creek, rivers and ponds.
- Blue Spot Goby – common in coastal drainages across southern Australia from Moreton Bay in Queensland to the Murchison River of Western Australia.
- Big Headed Goby – coastal rivers from Esperance in the east to Moore River to the north-west. It also penetrates inland waters (e.g. Warren, Scott and Blackwood Rivers) and is found in Lake Jasper in the far southwest.
- Swan River Hardyhead – coastal drainages of southwestern Australia from the Pallinup River in the east to the Moore River in the north-west.

Restricted to a limited area east of Albany
- Common Jolitail – widely distributed across the southern hemisphere at Australia, Lord Howe Island, New Zealand, Chile, Argentina, Tierra del Fuego and Falklands Islands. In southwestern Australia it is restricted to coastal streams between Albany and Esperance.
- Spotted Mountain Trout – widely separated populations in southeastern and southwestern Australia. In the latter it is restricted to a few streams near Albany, including the Goodga and Kalgan Rivers.

Eastern distribution terminating at the Albany district
- Nightfish – coastal streams, lakes and ponds of southwestern Australia, between the Albany district and Moore River.
- Freshwater Cobbler – coastal drainages of southwestern Australia from the Frankland River on the south coast to the Moore River north of Perth.

Balston’s pygmy perch – southern coastal area of southwestern Australia between Two Peoples Bay and the Blackwood River, inhabits coastal streams, lakes, ponds and swamps.
Morgan et al. (1996) reported both the Western Pygmy Perch and Balston's Pygmy Perch from the Goodga River (Western Australian Museum records), which adjoins the Angove system. The Big Headed Goby is widely distributed throughout coastal rivers of the southwest, but generally occurs in low abundances in fresh/brackish water systems. It may be in the lower Angove system, but was not recorded in this study.

Given these past and current records of fish from the Angove and adjoining Goodga River systems, it must be assumed for the purpose of determining environmental flows that all eight species indicated as likely to occur (Table 5) are present in the system.

2.5.2 Distribution of Freshwater Species within the Angove System

The Angove system may be divided into four distinct sections or reaches, the hydrology, geomorphology and water quality of that will influence the distribution of fish species:

1. Upper, faster flowing reaches containing natural waterfalls and Clear Pool;
2. Middle reaches above Angove Lake and below the waterfalls;
3. Angove Lake and flooded woodland/scrubland; and
4. The drain/lower river between Angove Lake and the outlet to the sea at Two Peoples Bay.

Reach 1. This consists of the shallower, faster-flowing upper reaches of Angove Creek, including Clear Pool. No fish were recorded from Reach 1, including within, immediately above and below the pipehead dam and above and below the water treatment plant. It is likely that natural, impassable waterfalls have restricted fish from the upper reaches of the river system.

The pipehead dam at Clear Pool currently forms a barrier to fish passage, however, there are natural waterfalls downstream of Clear Pool that also would prevent fish passage. Without physically walking the length of the system, the exact location of the cut-off in fish distribution is difficult to determine. Also, the cut-off may vary depending upon flood intensity in any year.

For instance, in some years some waterfalls will be washed-out in a bankfull flood allowing fish passage, but the absence of a flood of sufficient magnitude may make these waterfalls impassable in other years. There are waterfalls downstream of the water treatment plant that would be impenetrable to fish under most circumstances.

Reach 2. This reach consists of the wider, slow-flowing natural river channel connecting Angove Lake to the upper reaches. The channel here is up to 20 m wide and several metres deep with steep banks and overhanging vegetation. This morphology, combined with the dark-coloured water makes it difficult to fish effectively. Species preferring these conditions include the Common Jollytail and Spotted Mountain Trout. Migratory species will have to pass through Angove Lake to access this part of the system. These species will be restricted from Reach 1 by the waterfalls, but may progress into Reach 1 under certain circumstances (as described above).

Reach 3. This part of the Angove system consists of the permanently inundated basin and seasonally inundated woodland/scrubland margins of Angove Lake. The lake has a surface area of approx. 120 ha (ANCA 1993), is relatively shallow (1 – 2 m deep on average), with a firm sandy bottom overlain by deposits (~30 cms) of peat/detritus, most likely derived from B小微企业articulata, which is the dominate vegetation in the deeper areas.
A variety of reeds/rushes, aquatics and shrubs also occur in the shallow margins and seasonally-inundated parts of the wetlands in the Angove/Goodga system. Species include Leptocarpus scariosus, L. coangustatus, Bauema juncea, B. pretisi, Restio sp., Schoenus brevifolius, Juncus pallidus, J. capitatus, J. kraussii, the aquatic Triglochin procera, and closed scrub of Agonis juniperina, A. linearifolia, Melaleuca thymoides, Gahnia trifida, Kunzea aff. ericifolia and Hakea sp. (ANCA 1993). The majority of Angove Lake is vegetated, with small areas of open water. Migratory fish that occur in Reach 2 will have to pass through Angove Lake to reach the sea. The lake would also provide a suitable permanent habitat for most freshwater species likely to occur in the system.

Reach 4. This consists of (a) the man made drain connecting Angove Lake to Gardner Creek, and (b) the lower reaches of Gardner Creek from where the junction with the drain to the outflow at the sea. The channel connecting Angove Lake to Gardner Creek was constructed to reduce flooding of low-lying cleared land around the lake. The date of construction is not known, however, the presence of a narrow band of mature Melaleuca trees and mixed shrubs/reeds/rushes along the drain suggests the channel is quite old. The channel is meandering, approximately 10 m wide and up to 1.5 m deep, holding dark-coloured water. In appearance it differs little from the lower reaches of Gardner Creek. Approximately mid-way along the drain between Angove Lake and Gardner Creek there is a solid causeway across the drain, of rock and earth construction, connecting farmland on either side of the drain. There is a ~ 800 mm diameter pipe through the causeway, but the bottom of this pipe is at least 1 m above the thalweg of the drain. The causeway effectively forms a weir that regulates water levels in Angove Lake; water levels cannot fall below the bottom of the pipe.

Presumably, prior to construction of the drain, there was no distinct outflow channel, but there would have been sheet-flow from Angove Lake to Gardner Creek through the low-lying closed scrub. Gardner Creek connects Gardner Lake (and the Angove system) to the sea. The mouth of the channel is seasonally closed by a sand bar, which develops each spring and remains through summer until it is naturally eroded in winter by wave action and the build-up of water in the channel.

However, it is usually opened by hand to prevent excessive flooding. Backflow of saline water into Gardner Lake occurs, and as a result the lake is sub-haline, with an mean September salinity of 1.5 ppt. Angove Lake does not appear to be influenced by saline backflow; presumably there is a sufficient gradient and head from Angove Lake to prevent this occurring.

A range of freshwater species of fish as well as those with recent marine origins (e.g. Western Minnow, Swan River Goby, Big Headed Goby, Swan River Hardyhead) inhabits the drain and Gardner Creek. It also provides suitable habitat for the Western Pygmy Perch. Migratory species, such as Spotted Mountain Trout and Common Jollytail would have to pass through this area to get to Reaches 2 & 3 of the Angove system. A number of marine species are also reported to breed in the lower reaches of Gardner Creek; Yellow-eye Mullet (Aldrichetta forsteri), Sea Mullet (Mugil cephalus) and Black Bream (Mylis butcheri) (ANCA 1993; Coy unpub. data).

2.5.3 Ecology, Life Histories & Habitat Requirements of Freshwater Species

To understand how changes in flow regime may affect individual species of fish, a review of the life history requirements of all species likely to be in the Angove system was prepared. Some species have been extensively studied, whilst there is little information on other species.

Endemic Freshwater Species

Western Minnow

(Galaxias occidentalis Ogilby)

This species is one of the most widely distributed endemic species in south-west Western Australia, with a range extending from Winchester, about 150 km north of Perth, to Waychinicon Creek, 80 km east of Albany (Allen, 1989). Within this area, the Western Minnow occurs in rivers, streams, lakes, pools, and it readily invades seasonal creeks and swamps connected to permanent water. It is often found at the base of waterfalls (and V-notch gauging weirs) where the water is fast flowing and well oxygenated. This may indicate a preference for these conditions, or reflect fish that are prevented from continued upstream movement by a physical barrier. Fish have been observed jumping through V-notch weirs and ‘crawling’ up wet rock faces in an attempt to traverse barriers (ARL, 1990). The species likes both open water and enclosed areas amongst riparian vegetation. Terrestrial insects form a major component of the diet, although dipteran larvae and pupae, and microcrustacea (cladocera and copepods) are also consumed. Recent work suggests that the Western Minnow feeds at night on freshwater shrimp (Fairhurst, unpub. data, cited Morgan et al., 1996).

A study of this species in the Collie River reported that at the end of the first year, males and females grow to approximately 70 and 75 mm respectively, and 90 and 100 mm at the end of their second year. They are sexually mature at the end of their first year, and some fish survive to spawn in the following year and a very limited number into a third, fourth and even a fifth year. Fish move upstream into tributaries (particularly seasonal creeks that start to flow) to spawn on flooded vegetation.

This occurs between June and late September, with a peak in August when water temperatures start to increase. Females produce approximately 900 eggs, although fecundity increases with age. Watts et al. (1995) studied the genetic structure of the Western Minnow in the Canning and North Dandalup river systems, and observed that populations on the Darling Scarp and Swan Coastal Plain were separate and non-mixing. It was suspected that scarp populations moved into tributary creeks on the scarp to breed, whilst coastal plain populations moved into drains and wetlands on the coastal plain.

Spotted Mountain Trout

(Galaxias truttaceus Valenciennes)

This species is known from widely separated populations in southeastern and southwestern Australia. The former includes coastal streams from Wilson’s Promontory westwards to the Glenelg River in Victoria, King, Flinders and Clarke Islands in Bass Strait, low elevation streams around the Tasmanian coast, and several lakes on the central Plateau of Tasmania including Great Lakes, Julian Lakes, and Bronte Lagoon. In Western Australia the species is found in a few streams near Albany, including the Goodga/Angove system and Kalgan River.

The Spotted Mountain Trout inhabits still or slow-flowing waters at low elevations close to the sea. It is most abundant along the shore margin in rocky areas or around log snags and debris. The species has a marine juvenile stage, indicative of a diadromous life cycle. Adults migrate downstream to estuaries/bays in autumn during high (spring) tides to spawn their eggs on dense terrestrial vegetation that is flooded by the spring tide. During the next two weeks, the eggs develop out of water in humid conditions.
Hatching then occurs when a second series of high tides wash over the eggs and the larvae are swept out to sea. The juveniles eventually migrate back to shore and enter freshwater systems, generally during spring. The diet of adult fish in freshwaters consists mainly of aquatic and terrestrial insects.

**Common Jollytail**  
*Galaxias maculatus* (Jenyns)

This species is widely distributed in the Southern hemisphere, found in Australia (including Tasmania), Lord Howe Island, New Zealand, the Chatham Islands, Chile, Argentina, Tierra del Fuego, and the Falklands Islands. In Australia there are widely separated eastern and western populations. The eastern range is from Brisbane southwards in coastal streams of New South Wales, Victoria, Tasmania (including King and Flinders Islands in Bass Strait), and South Australia as far west as Port Lincoln. In Western Australia, it occurs in coastal streams between Esperance and Albany.

It is most common in still or slow-flowing waters, mainly in streams, rivers and lakes within a short distance of the sea. It sometimes occurs in brackish waters and can survive salinities up to 50 ppt. There are both landlocked and diadromous populations. Adults of the latter migrate downstream to estuaries/bays in autumn during high (spring) tides to spawn their eggs on dense terrestrial vegetation that is flooded by the spring tide. During the next two weeks, the eggs develop out of water in humid conditions.

Hatching then occurs when a second series of high tides wash over the eggs and the larvae are swept out to sea. The juveniles eventually migrate back to shore and enter freshwater systems, generally during spring. Landlocked, lake dwelling populations undergo local migrations up tributary streams during floods. Eggs are then deposited on flooded vegetation and development occurs once waters subside.

Hatching then takes place during subsequent floods, with larvae presumably washed downstream into the lake.

The diet of adult fish in freshwaters consists of a wide range of aquatic and terrestrial insects and crustaceans.

**Pygmy perch**  
*Edelia vittata* (Castelnau)

This, together with the Western Minnow, is the most widely distributed endemic fish species in southwest Western Australia, with a range from Moore River, north of Perth, to Philips River, east of Albany. This species is common in rivers, streams, and lakes, and readily re-invades seasonal wetlands via flood-ways and up seasonal creeks/drains. The species is often associated with riparian/emergent vegetation and rarely occurs in open water.

The diet consists of a wide range of small benthic invertebrates, especially dipteran larvae, ostracods, copepods and Trichoptera (caddisflies) larvae, but also terrestrial insects.

During winter, fish move from the river into either adjacent floodwaters or tributary creeks in preparation for breeding. Spawning takes place between late winter and late spring (July-November), and females may spawn more than once in a breeding season. Allen (1989) notes that females lay batches of 20 – 60 eggs at 6 – 8 week intervals, and the adhesive eggs sink and attach to the bottom or flooded vegetation. The eggs hatch and the larval stage lasts approximately 2 – 3 weeks. Sexual maturity is attained by both sexes at the end of the first year of life. The majority of fish live to three years, although fish up to six years old have been recorded (Pen & Potter, 1991c).
Balston's Pygmy Perch
(*Nannatherina balstoni* Regan)

This species is found only in Western Australia and is distributed between Two Peoples Bay in the east and Margaret River in the west (with an isolated population at Gingin, approx. 100 km north of Perth). The species is generally restricted to the coastal peat flats, but was relatively frequently encountered in the acid peat wetlands of the Muir and Unicup catchments (Storey, unpub. data). It is the rarest of all endemic freshwater fishes of southwestern Australia.

It is typically found in shallow, isolated pools with dark acidic water (pH 3.0 – 6.0), but also occurs in larger rivers and lakes and in seasonal creeks. In winter and spring the species is regularly found in inundated riparian vegetation, where it presumably feeds and spawns. Larvae and juveniles feed predominantly on cladocerans, while adults feed predominantly on terrestrial invertebrates (*e.g.* arachnids, adults of Hymenoptera, Coleoptera and Diptera). Males and females generally reach sexual maturity by the end of the first year, and spawn once between June and September, with a peak in mid-July to August when water levels are highest.

Native Species with Recent Marine Origins

Swan River Goby/Blue Spot Goby
(*Pseudogobius olorum* Sauvage)

The Swan River Goby has a wide distribution from the Murchison River, north of Perth, as far east as Esperance. It occurs in estuaries, rivers, and both freshwater and hypersaline lakes (Morgan *et al.* (1996). It can penetrate long distances inland (*i.e.* upper reaches of the Blackwood River, Wheatbelt Region), and occurs in some isolated lakes. It is usually found over mud bottoms, and sometimes amongst weeds or adjacent to rocky areas.

In the Swan River it consumes algae and mats of fungi and bacteria, ingesting invertebrates only in winter, although Fairhurst (1993; cited Morgan *et al.* (1996)) noted that fish in Swan Coastal Plain lakes consumed invertebrates in all seasons.

The species life cycle is less than a year, and the species spawns in spring and autumn, and to a limited extent in summer. Progeny of the spring spawning will reproduce in the following autumn when only five months old, and *vice versa* for progeny of the autumn. Some individuals will survive to spawn a second time.

The female lays approximately 150 eggs on the underside of a solid object (*rocks, logs etc*), and the male guards and fans the eggs during the incubation period, which lasts about four days. The larvae are planktonic and are swept downstream into estuaries, from where they juveniles migrate back into the rivers. Some populations are landlocked.

Swan River Hardyhead
(*Leptatherina wallacei* Prince, Ivantsoff & Potter) (previously *Atherinosoma wallacei*)

The Swan River Hardyhead occurs from the Moore River, north of Perth, to the Pallinup River, west of Bremer Bay. It inhabits clear, flowing freshwater streams and upper reaches of estuaries with reduced salinities. It is often seen in schools near the surface or around the shoreline vegetation and amongst log debris.

It ingests planktonic crustacea, terrestrial insects, polychaetes and unicellular algae. In the Swan Estuary, males and females attain lengths of 45 and 55 mm at the end of their first year, when they are sexually mature. Few fish last beyond one year. They have a protracted spawning period that peaks in late spring.
Big Headed Goby  
(*Aforcogobius suppositus* Sauvage)  
(previously *Favonigobius suppositus*)

The Big Headed Goby also has a wide distribution from Moore River, north of Perth, as far east as Esperance. It occurs in estuaries, rivers, streams and coastal lakes. It can penetrate inland waters (*i.e.* Warren, Scott and Blackwood rivers (Morgan *et al.* (1996)). It has a strong preference for heavy cover (Gill & Humphries, 1995), and consumes Hemipterans (waterbugs), Diptera larvae, bivalves, terrestrial insects, Ephemeroptera (mayflies), Trichoptera (caddisflies) and small fish (Young, 1994; cited Morgan *et al.*, 1996). The length of the life cycle and the reproductive biology is not known.

Morgan *et al.* (1996) suggest that the life cycle probably lasts two years, the species breeds after one year, and males guard a nest under stones or amongst aquatic macrophytes where several females have laid eggs. Breeding probably occurs between late spring and early summer.

**Introduced Species**

No introduced species of fish were recorded from the Angove system in this study. However, the literature suggests that the potential exists for non-native species to be present. Rainbow Trout (*Oncorhynchus mykiss*), Brown Trout (*Salmo trutta*), Redfin Perch (*Perca fluviatilis*) and Mosquitofish (*Gambusia holbrooki*) all occur in the Albany area. Both species of trout are present in the King River, Rainbow Trout are in the Waychinicup River, and Rainbow Trout, Redfin Perch and Mosquitofish all occur in the Kalgan River. There are no confirmed records of introduced species from the Angove/Goodega systems, however, Rainbow Trout were introduced to the Two Peoples Bay area by the Acclimatisation Committee of Western Australia in 1913 and 1916.

Trout were released at regular intervals to streams, dams and lakes by the Albany, Denmark and Plantagenet Acclimatisation Society that functioned between 1955 and 1964 (Coy, unpub. data). This practice ceased in the Angove and Goodega systems after the reserves were gazetted (Coy, unpub. data).

**2.5.4 Fish Environmental Water Requirements (EWRs)**

Generally, for all species in the Angove system, there is a pre-requisite for permanent water, both in the creeks and the lake. Although several of the species readily invade seasonal creeks to reproduce, none of the species have adaptations to withstand desiccation (such as occurs in the Salamanderfish (**Lepidogalaxias salamandroides**) and Black-stripe Minnow (**Galaxiella nigrostriata**)). Therefore, increased abstractions must ensure permanent water is maintained in the system.

Juveniles and adults of all species seem to have generalist diets, consisting of aquatic and terrestrial insects and invertebrates, with some species also consuming zooplankton and crustacea. Given the generalist nature of the diets it is unlikely that the diet of any species will be limited by an altered flow regime to the extent whereby the species is unable to switch diet to survive.

Therefore, components of the biology of the species most likely to be affected by altered flow regime are fish migration and reproduction.

**Endemic Freshwater Species**

The freshwater species broadly may be placed into three groups of differing life history characteristics, which have particular flow requirements:
Group 1. Western Minnow - Fish move upstream into tributaries (particularly seasonal creeks once they start to flow) to spawn on flooded vegetation. This occurs between June and late September, with a peak in August when water temperatures start to increase. This is a critical phase of the life cycle of this species.

Until the existence of this species in the Angove catchment has been confirmed, water levels should be maintained so that migration is possible, and riparian vegetation is flooded during this time.

Group 2. Pygmy Perch & Balston’s Perch - spawning occurs in inundated riparian vegetation between June and September, with a peak in mid-July to August, when water levels are highest. Again, this is a critical phase. Water levels in the creeks and lake must be sufficiently high so that there is flooded riparian vegetation into which the fish may move to spawn.

Group 3. Spotted Mountain Trout and Common Jollytail – these species inhabit still or slow-flowing waters at low elevations close to the sea and migrate downstream to estuaries/bays in autumn. Juveniles eventually migrate back to shore and enter freshwater systems, generally during spring. Flows must be sufficient to allow passage of adults downstream, through Angove Lake and the drain (and culvert) to the sea in autumn, and to allow juveniles back up the system in spring. The length of time in winter over which the sand bar is open should not be reduced as this may prevent adults reaching the sea in time to spawn, and/or juveniles reaching freshwater before the bar is closed.

The probable existence of landlocked populations of the Common Jollytail in Angove Lake and Reach 2, means flood flows down Angove Creek must be sufficient to allow local migrations up the creek and must flood vegetation for eggs to be deposited upon.

These floods then must subside to allow development to occur (approx. two weeks duration), with return floods after approximately two weeks to wash hatched larvae into the channel.

Native Species with Recent Marine Origins

The three species with recent marine origins (Swan River Goby, Big Headed Goby and Swan River Hardyhead) inhabit the lower reaches of the system, although their distributions may extend into the lake. It is likely that conditions in the Angove Drain and Gardner Creek will remain suitable, even with increased extractions from Angove Creek. Water levels will be maintained by flows from Moates Lake and backflow from the sea, therefore, current habitat will be maintained, and any increase in salinity is unlikely to have a detrimental effect on these species because they are all able to withstand brackish to saline conditions.

Introduced Species

With respect to EWRs in the Angove system, trout (if present) will be more mobile and better able to traverse obstacles (waterfalls/low weirs) than native species. Therefore, their distribution will likely be more favoured by decreased flows. However, shallower water in summer will act against trout as they are less well adapted to withstand higher water temperatures (e.g. > 22°C), and prefer deeper, cooler waterbodies to avoid these conditions in summer months. Trout, being piscivorous could have detrimental effects on native species if their numbers increase. Pusey et al. (1989) noted that flow regulation, and the absence of large flushing flows in winter seemed to favour the distribution of Mosquitofish. If this species is present in the systems, increased extractions and reduced flushing may result in an increased abundance of Mosquitofish. This species is also known to compete with native species (Morgan et al., 1996).
Summary of Fish EWRs

The actual water required to meet fish EWRs was determined predominantly through the use of the Manning’s Equation. The Manning’s Equation was used to calculate what water volumes would be required to maintain a stage height of 40 cm to allow species to traverse in-channel obstacles. For Galaxias, it is of critical importance that adequate water for seasonal migration is available during August-October. Outside these months EWRs would be met by baseflows (as recommended for macroinvertebrates).

During winter, increased flows of up to 135 ML (to reflect the historic flow regime) would be required for fish migration; i.e. higher flows would “drown-out” natural obstructions etc) allowing species such as Galaxias to attach eggs to the inundated bank-side vegetation upstream. Although there are a number of artificial barriers to fish migration, the frequency of natural barriers is high. For example, there are about five falls per 100m in the upper reaches that most native fish would be incapable of traversing.

<table>
<thead>
<tr>
<th>EWRS FOR FISH MIGRATION &amp; REPRODUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
</tr>
<tr>
<td>35</td>
</tr>
<tr>
<td>32</td>
</tr>
<tr>
<td>35</td>
</tr>
<tr>
<td>34</td>
</tr>
<tr>
<td>35</td>
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<td>34</td>
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<tr>
<td>35</td>
</tr>
<tr>
<td>135</td>
</tr>
<tr>
<td>131</td>
</tr>
<tr>
<td>135</td>
</tr>
<tr>
<td>34</td>
</tr>
<tr>
<td>35</td>
</tr>
</tbody>
</table>

2.6 Water Quality Parameters

Although outside the specific goal of EWR releases, in many regulated systems of the southwest, provision for EWRs can also ameliorate water quality problems, which arise from poor catchment management. Selected physical and chemical water quality parameters were measured between 0900 and 1700h at all seven sites in Angove Creek. Parameters measured in the field and equipment used are indicated in Table 7. Nutrient (total nitrogen and total phosphorus) and alkalinity (pH) analyses were conducted by the Environmental Chemistry Laboratory, Chemistry Centre (WA). Results are presented in Table 8.

Based on the June 1999 sampling, all sites were characterised by high biological water quality. Salinities ranged from 473 - 612 μS/cm (0.24 – 0.32 ppt) in Angove Creek and 849 μS/cm (0.46 ppt) in Angove Lake. Upstream intrusion of a salt “wedge” from the coast was evident in brackish bottom waters of Angove Drain (site 6).

At the drain, salinities were relatively high; 1098 μS/cm (0.61 ppt) in surface waters and 19,900 μS/cm (18.34 ppt, equivalent to approx. half the salinity of seawater) in bottom waters.

Turbidities were moderate (0.5 – 52 NTU), though slightly elevated in bottom water of Angouve Drain (148 NTU). pH ranged from acidic to neutral (pH 5.3 - 7.0) and daytime, dissolved oxygen levels were high (11.2 – 12.9 mg/L) in all but bottom waters of Angove Drain (3.1 mg/L).

Redox potentials (ORP) were low (368 – 378 mV). An increased redox potential is indicative of an increased chemical and biological demand for oxygen.
Nutrient levels were low (TN 0.17 – 0.75 mg/L, TP <0.01 – 0.04 mg/L), well below statutory guidelines (EPA 1993). The slightly elevated total nitrogen concentrations recorded in downstream reaches, were probably a consequence of both farm runoff and uncontrolled livestock access to the channel (e.g. Sites 6 – 7) and release from decay of native macrophytes (e.g. Site 5 – Angove Lake).

Due the existing high quality of waters in the Angove system, specific EWRs to maintain water quality were not considered necessary.

Table 7. Physico-chemical parameters measured during the June 1999 field survey; equipment and precision.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>PRECISION/UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>0.05 °C</td>
</tr>
<tr>
<td>Dissolved oxygen (DO)</td>
<td>0.1 mg/L (8 0.1 % saturation)</td>
</tr>
<tr>
<td>Turbidity</td>
<td>0.5 NTU</td>
</tr>
<tr>
<td>Salinity (ppt)</td>
<td>0.1 ppt</td>
</tr>
<tr>
<td>Conductivity (mS/cm)</td>
<td>0.1mS/cm</td>
</tr>
<tr>
<td>Alkalinity / pH</td>
<td>0.01 pH units</td>
</tr>
<tr>
<td>ORP (Oxidation-Reduction Potential/Redox Potential)</td>
<td>1mV</td>
</tr>
</tbody>
</table>

Table 8. Results of water quality analyses, Angove Creek, June 1999.

<table>
<thead>
<tr>
<th>Site</th>
<th>Turbidity (NTU)</th>
<th>Temp (°C)</th>
<th>pH</th>
<th>Salinity (ppt)</th>
<th>Econd (µS/cm)</th>
<th>DO (mg/L)</th>
<th>Redox ORP (mV)</th>
<th>Total N (mg/L)</th>
<th>Total P (mg/L)</th>
</tr>
</thead>
</table>
2.7 Riparian Vegetation

Local riparian vegetation condition was assessed using the rapid assessment methodology of Pen & Scott (1995). This was done in order to estimate the extent of ecologically significant remnant riparian vegetation and the likely impact of flow regulation. The vegetation assessments were conducted at all seven sites in Angove Creek (Figure 1).

Allocation of water to meet riparian vegetation EWRs is also consistent with general objectives of the EPA that seek to "maintain the abundance, species diversity, geographic distribution and productivity of vegetation communities" and to protect Declared Rare and Priority Species in accordance with the Wildlife Conservation Act 1950.

The riparian vegetation condition was assessed as healthy (e.g. classed as A2 - A3) at most sites (Table 9). As such, it is a critically important component of the landscape (Danks 1991). High insect production in these areas is likely to support much of the terrestrial fauna, including the Noisy-scrub Bird. It is also possible that these riparian zones may provide suitable habitat for Gilbert's Potoroo.

Where the vegetation was of lower quality (e.g. Angove Drain classed as B2), factors other than adequate water levels were deemed responsible (i.e. uncontrolled livestock access to riparian zones, clearing of native vegetation).

Vegetation of the riparian zone can either intercept groundwater or directly extract channel water. It is likely that most of the riparian vegetation was more heavily reliant on groundwater (L. Baddock, WC, *pers comm.*) and in many reaches of the Angove, which are bedrock controlled, would not have access to water in the channel.

Therefore, in the EWR model there was no specific surface water allocation for riparian vegetation, aside from the flushing flow for channel maintenance (of approximately 155ML and 18 hours duration, once every three years). A flushing flow would also inundate riparian zones in some reaches, stimulating seed-set and recruitment.

It was considered that some reduction in channel flow would not have a direct impact on riparian vegetation. However, the salinity tolerance of *Baumea articulata*, the dominant emergent on Angove Lake, is ~ 3 ppt (Froend *pers comm.*). There is thus the need to make sure that the gradient and head from Angove Lake is sufficient to prevent saline backflow from Gardner Creek. Backflow of saline water up Angove drain may also impact riparian vegetation along the drain (e.g. *Melaleuca* & reed/rush species).

These sedgelands are likely to provide habitat for the Australasian Bittern (*Botaurus poiciloptilus*), a declared threatened species (Western Australian Wildlife Conservation Act).


<table>
<thead>
<tr>
<th>Site code</th>
<th>Riparian assessment</th>
<th>Condition</th>
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<tbody>
<tr>
<td>1</td>
<td>A2</td>
<td>Near pristine: some weeds</td>
</tr>
<tr>
<td>2</td>
<td>A2</td>
<td>Near pristine: some weeds</td>
</tr>
<tr>
<td>3</td>
<td>A2</td>
<td>Near pristine: some weeds</td>
</tr>
<tr>
<td>4</td>
<td>A2</td>
<td>Near pristine: some weeds</td>
</tr>
<tr>
<td>5</td>
<td>A2</td>
<td>Near pristine: some weeds</td>
</tr>
<tr>
<td>6</td>
<td>B2</td>
<td>Heavily weed infested</td>
</tr>
<tr>
<td>7</td>
<td>A3</td>
<td>Slightly disturbed: local weeds</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EWRS TO MAINTAIN RIPARIAN VEGETATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Would be adequately met by baseflows together with channel maintenance flows.</td>
</tr>
<tr>
<td>Important to limit the backflow of saline water up Angove Drain.</td>
</tr>
</tbody>
</table>
3. RECOMMENDED FLOW REGIME FOR ANGOVE CREEK

3.1 Desired Future State
The determination of the desired future state (DFS) of any river is a process which will also partially determine the required flow regime. At present, Angove Creek is considered to be in “good” ecological condition. Though the creek is impounded, the underlying ecological processes and biodiversity are not considered to differ substantially from the more pristine state. Typically, impoundment results in reduced summer flows, which generally causes significant stress and localised loss of biodiversity. In Angove Creek however, summer baseflows have been maintained, supporting both the fauna and underlying ecological processes.

The present state is characterised by low ecological risk. In this instance, flows for EWRs should be designed to reduce, in the longer-term, potential risk from proposed increases in abstraction rates. However, the determination of the DFS of any river system is typically influenced by socio-political factors. The EWRs presented here are the initial “request” for water to the environment. The final allocation (the EWP) is determined after social, economic and industrial users have also been considered. EWPs were beyond the scope of this present study. The following recommended flow regime is designed to maintain the existing aquatic ecosystems with continued low ecological risk.

3.2 Summary of EWRs
As discussed earlier, EWRs of important water dependent components of the aquatic ecosystem were calculated. The major in-stream flow issues considered were:

1. Flushing flows for channel maintenance and inundation of riparian vegetation in some reaches;
2. Flows to maintain water levels in Angove Lake and control upstream saline water intrusion from the coast;
3. Flows to maintain macroinvertebrate biodiversity;
4. Flows to enable native fish migration and spawning;
5. Maintenance of habitat for the Noisy-Scrubbird, Australasian Bittern and (potentially) Gilbert’s Potoroo, through preservation of existing riparian vegetation;

Channel surveys of hydraulic geometry, analysis of the current and historic flow record and the holistic methodology were used in a “building block approach” to determine the monthly EWRs for the Angove Creek system.

3.3 Recommended Monthly Flow Allocations
A model for a modified flow regime was constructed based on the desired future state (DFS) of Angove Creek. The DFS was considered to be maintenance of existing ecological values, protected at a low level of risk. A baseflow of about 35 ML/month (equivalent to about 1.15 ML/day, “delivered” at the old gauging station) was considered the minimum necessary for the maintenance of benthic invertebrates and native fish at downstream sites.

The monthly flow allocations, for specific ecological parameters of the Angove Creek, as determined for one year, are presented in Tables 10.
Table 10. Recommended monthly flow allocations to meet estimated EWRs of Angove Creek downstream from Clear Pool, with a low level of ecological risk.

<table>
<thead>
<tr>
<th>Month</th>
<th>Baseflows</th>
<th>Fish passage</th>
<th>Channel maintenance</th>
<th>Lake water levels</th>
<th>Seasonal adjustment</th>
<th>TOTAL (ML)</th>
</tr>
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<tbody>
<tr>
<td>Jan</td>
<td>35</td>
<td></td>
<td></td>
<td>35</td>
<td></td>
<td>35</td>
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<tr>
<td>May</td>
<td>35</td>
<td></td>
<td></td>
<td>9</td>
<td>62</td>
<td>62</td>
</tr>
<tr>
<td>Jun</td>
<td>34</td>
<td></td>
<td></td>
<td>6</td>
<td>75</td>
<td>75</td>
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<td>8</td>
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<td>Sep</td>
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<td>Nov</td>
<td>34</td>
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<td>31</td>
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<td>35</td>
<td></td>
<td></td>
<td>35</td>
<td></td>
<td>35</td>
</tr>
</tbody>
</table>

Total annual EWR = 882 ML (increasing to 902 ML: 1/3 years)

1. Baseflows are to maintain flow in riffles of at least 5cm in depth. This is to maintain benthic invertebrates (riffle zones are areas of high insect production) and ensure baseflow conditions for native fish.

2. Increased flows are required during August, September and October to enable the migration of native fish (i.e., these higher flows will “drown-out” many natural obstacles) and inundate streamside vegetation where some species attach eggs. Based on requirements of native fish species where a minimum stage height of 35cm was considered necessary the migration.

3. The 155ML for August is to coincide with seasonally-elevated water levels to cause a flushing flow over an 18 hour period. These flows one year in three, outside this period, flows of 135 ML are required.

4. These flows are to maintain Angove Lake water levels. Although the lake is considered a function of groundwater, these flows are designed to exceed evaporation rates (by each month) within the lake.

5. Seasonal adjustments are to ensure EWRs reflect the historic flow regime.

The annual water needs were calculated from the sum of the flow requirements throughout the year and the additional small and medium-sized floods. It should be noted, that EWRs can only be applied to the defined water dependent ecosystems and there may be other, as yet, undefined ecological parameters requiring specific water allocation.

The recommended total EWR allocation for Angove Creek is 882 ML during average years, increasing to 902 ML in “wet” years (Table 10). Results from the current study indicated that the EWRs of reaches surveyed were being adequately met by existing flows.

Channel Maintenance Flows

Under the modelled flow regimes, a large flow of 155 ML during August once every three years, is recommended to coincide with seasonally-elevated water levels resulting in a flushing flow. This flow would maintain the active channel, flush material aggraded in pools and, in places, inundate riparian vegetation. The present pumping system would do little to reduce the duration and extent of these large flood-flows.
Flows to Maintain Water Levels in Angove Lake

Water levels in Angove Lake were considered to be partly a function of groundwater inputs. However, in the absence of detailed hydro-geological data, contributions from groundwater could not be factored into EWR estimates. Therefore, EWRs were calculated solely as monthly surface flows required to exceed the monthly evaporation rates of water from the lake. It was estimated that 6 ML/month in winter and up to 35 ML/month in summer is required to maintain water levels in the lake.

Benthic Macroinvertebrates in Riffle Zones

Aquatic invertebrates are an important component of riverine food webs. Typically, secondary production of invertebrates is elevated in riffle zones (Davies 1993) and riffles are the most vulnerable habitats to abstraction. A baseflow of approximately 35 ML is required to provide riffle habitat for benthic macroinvertebrates and maintain the Angove as a perennial system.

Fish Passage and Spawning

Four species of fish were recorded from the Angove system in June 1999; Spotted Mountain Trout (Galaxias truttaeus), Common Jollett (Galaxias maculatus), Swan River Goby (Pseudogobius olorum) and Swan River Hardyhead (Leptatherina wallacei). A baseflow of approximately 40 ML is required to support the movement of these native fish. Increased flows (up to 135 ML) are required between August - October (to reflect the historic flow regime) for spawning migration by these species and to inundate streamside margins to allow some species (e.g. Galaxias) to attach eggs to the flooded bank-side vegetation.

Water for Riparian Vegetation (active growth, seed-set and subsequent recruitment).

The riparian zone of the majority of the Angove system classified as “near pristine” (A2 in the condition index of Pen and Scott 1995) and, as such, is a critically important component of the landscape that has not been degraded by the existing regulated flow regime. It is likely that much of the riparian vegetation is reliant on groundwater. Many reaches of the Angove are bedrock controlled where vegetation would not have access to water in the channel. Therefore, there is no specific recommendation for surface water allocation for riparian vegetation in either model.

Maintenance of Noisy Scrub Bird habitat & potential habitat for Gilbert’s Potoroo.

High invertebrate production in riparian zones is likely to support much of the terrestrial fauna including the endangered Noisy Scrub Bird (Atrichornis clamosus) (Danks 1991). There is also the potential for riparian zones of the Angove to provide habitat for the extremely rare Gilbert’s Potoroo (Potorous tridactylus gilberti) (A. Danks, CALM Albany, pers. comm.).

Based on the above assertion that riparian vegetation predominantly intercepts groundwater, there are no specific recommendations for provision of surface water for terrestrial fauna habitat in either model.

Water Quality

Water quality was not a major issue for the Angove catchment, based on the June 1999 field survey. Only slightly elevated nutrient levels were measured in the downstream sites however modification of flows was not considered an appropriate tool for nutrient management; a catchment management issue.
Flows to Control Upstream Saline Water Intrusion from the Coast

Saline water intrusion, up Gardner Creek, is largely outside the influence of downstream flows. However, the position of the culvert in Angove Drain was considered responsible for the extent of the saline intrusion up Angove Creek. This culvert controls the water levels in Angove Lake probably to a greater extent than input from Angove Creek and it also regulates the extent of the upstream "wedge" of saline water. The gradient and head from Angove Lake must remain sufficient to prevent saline backflow up Angove Drain. Backflow of saline waters may degrade sensitive *Baumea articulata* sedgelands that fringe the lake. These sedgelands are likely to provide habitat for the Australasian Bittern (*Botaurus poicilloptilus*), a declared threatened species (Western Australia Wildlife Conservation Act).

3.4 Water Abstraction

Careful management of the abstraction is required given the proportion it represents of the total annual flows, is critical. With an increasingly modified flow regime, it is important that rates of rise and, particularly fall, of environmental flows do not exceed that of the natural hydrograph. In the latter case, this can lead to stranding of fish in side channels and pools and also to the slumping of saturated banks and associated loss of riparian vegetation.

Abstraction should *never* result in reaches of the river becoming dry. This would lead to localised extinction of aquatic fauna which, due to the extent of obstructions, may be prevented from re-colonising impacted reaches. Therefore, abstraction has to, at least in part, reflect the natural hydrology; *i.e.* higher rates in winter, reducing during summer.

It should be noted that the hydrological record for Angove was collected during a "dry" climatic cycle and that the trend appears to be one of decreasing total annual rainfall. The re-commissioning of gauging stations for the Angove is recommended.

3.5 Monitoring & Adaptive Management

It must be emphasised that the estimated EWRs for the Angove system are essentially a "best scientific guess". The EWRs have been formulated in the context of an incomplete ecological record (one field trip only) and limited hydrological data (1963 to 1982). In the absence of sound ecological understanding, the best available approximations of significant flow events and temporal patterns of flow should be used.

An important corollary of this is that the initial in-stream flow recommendations for most rivers should be regarded as first estimates (Davies *et al.* 1998).

Therefore it is critical that the proposed abstraction be considered in an adaptive management context (*e.g.* Adaptive Environmental Assessment and Management: AEAM). In adaptive management, the ecological consequences of the proposed increased abstraction should be carefully monitored and re-adjusted if required.

3.5.1 Recommendations for Monitoring EWRs of Angove Creek

Existing and future water supplies should include provision for environmental water requirements and monitoring of the success of the modified flow regimes should be incorporated into both planning and management processes. Ideally, monitoring the impacts of increased abstraction should include measurement of physical parameters, biological parameters and water quality parameters.
Recommendation 1
Levels of pool aggradation and channel stability in reaches downstream from the abstraction point should be monitored. At set points on the Creek, a photographic record and measurements of channel morphology should be maintained at a single site e.g. Site 3, Plates 6 - 8). In selected pools, the extent of sediment should be mapped (see Bunn _et al._ 1998). Sampling should be conducted during late summer.

Recommendation 2
Water quality parameters (including nutrient status) should be monitored both upstream and downstream from the abstraction point in Angove Creek and in Angove Lake and Angove Drain. Water quality parameters should include turbidity, dissolved oxygen pH, water temperature nutrients (total N and total P) and, in particular, salinity/conductivity. Water levels in Angove Lake should be monitored quarterly.

Recommendation 3
The extent of saline intrusions via the culvert in Angove Drain, immediately downstream from Angove Lake, should be monitored under any modified flow regime.

Recommendation 4
Aquatic fauna should be monitored annually to detect any changes in fish recruitment or macroinvertebrate community structure.

During late spring / early summer, fish should be sampled using a range of techniques (e.g. electrofishing, seine _etc_) designed to maximise the number of species collected. Fish should be measured and life stage determined. For comparative purposes, reaches sampled should include those possibly impacted by natural barriers. Sampling sites should include the two-mid reach sites sampled during the current study _e.g._ Site 3 (Plates 6 - 8) and 4.

Macroinvertebrates should be collected from representative reaches using the National River Health Program (NRHP see Appendix 2) protocol. Samples should be collected from Sites 2 (Plate 9), 3 (Plate 6 - 8) and 4 and compared to the existing NRHP database allowing an assessment of the health of Angove Creek.

Recommendation 5
The riparian vegetation should also be monitored at set photographic points, particularly in reaches where the banks are steep. In these areas, impacts on vegetation due to a reduction in water levels can be assessed providing an “early warning” and, if necessary, changes in flow management instigated before the impacts become more widespread. Under either flow regime, the riparian condition of Angove Creek from Clear Pool to Angove Lake, should be assessed during late summer, using the methods of Pen and Scott (1995). The six sites outlined in this study should be re-sampled.

Recommendation 6
A hydrological record for Angove Creek should be maintained. It is critical that flows are monitored, given the proportion the proposed abstraction represents of total flows.
Plate 6 (top left). Fixed point for photographic monitoring at sharp-crested V-notch weir of gauging station below treatment plant on Angove Creek (immediately upstream of Site 3). Such weirs form barriers to upstream migration of fish during periods of low to medium flows.

Plate 7 (top right). Flow (~0.012 m³/sec) over V-notch weir below treatment plant during April 2001.

Plate 8 (bottom left). Fixed point for photographic monitoring at Site 3, immediately downstream of V-notch weir, April 2001. Effect of February 2001 burn still clearly evident. Subsequent loss of understorey vegetation may make banks vulnerable to slumping during winter rains and potash runoff may increase algal blooms.

Plate 9 (bottom right). Fixed point for photographic monitoring at Clear Pool (Site 2). Photograph taken during low-flow period of April 2001.
4. LIMEBURNERS CREEK CATCHMENT

Limeburners Creek is a small, forested first-order creek 6km southwest of Albany (Plate 10). The creek has a small, ill-defined estuary in Shoal Bay in Princess Royal Harbour.

A pipehead dam was built approximately 40 years ago to augment groundwater supplies from the South Coastal borefield to the town of Albany. However, due to water quality problems, this source was not used between 1992 and 1998. In December 1998, the Water Corporation recommissioned this source with the installation of an additional temporary treatment plant at the South Coastal treatment plant.

Opportunistic sampling of the Limeburners Creek was conducted in June 1999 in conjunction with the Angove Creek sampling. Limeburners Creek was characterised by relatively pristine riparian vegetation (i.e. condition A1-A2 in the code of Pen & Scott 1995).

Flow rates were low, probably as a function of catchment size. The flow record (station 602041, 1954-1963) showed the creek to be perennial with MAF of about 500 ML. The lack of seasonality (e.g. coefficient of variation of monthly flows was 17%) indicated the overriding influence of groundwater in maintaining water levels in the creek.

Spot sampling revealed a system reasonably depauperate of aquatic fauna. No fish were collected and the biodiversity of macroinvertebrate fauna was extremely low, possibly due to the small size of the creek and the lack of habitat diversity.

These types of first and second order creeks are well represented elsewhere on the south-coast of Western Australia. Therefore, important water-dependent ecosystems or important components of these ecosystems were considered limited. The desired future state (DFS) for the creek was considered to be one that protected current condition / values at a low level of ecological risk. In this context, the only EWR was considered to be the provision of flow to ensure the creek remains perennial.

Due to the lack of seasonality of flows, it was concluded the creek could sustain a constant rate of abstraction throughout the year.

Due to the lack of important water dependent ecosystems in Limeburners Creek, monitoring the impact of abstraction is not considered necessary.

Plate 10. Limeburners Creek, immediately below the gauging station. Narrow channel with very steep banks, densely vegetated.
5. LIMITATIONS OF THE STUDY

EWRs are typically defined without complete ecological information. This is the case for both Angove Creek and Limeburners Creek where the field component of the work was a "snap-shot" study conducted during moderate flows. Generally, similar fieldwork during late summer would be required to assess the system during periods of increased ecological stress due to seasonally low water levels.

The EWRs determined in this report represent an initial "request" for water to the environment. The final allocation (the EWP) is determined after social, economic and industrial users have also been considered. EWPs were beyond the scope of this present study. The recommended flow regimes are designed to maintain the existing aquatic ecosystems with continued low ecological risk.

Acknowledgments:

Jim Lane (CALM) for supplying Angove Lake water level data and Alan Danks (CALM) for advice on Potoroos.
REFERENCES


APPENDICES
APPENDIX 1

Table A1. CALM water quality parameters and depth measurements recorded from Angove Lake.

<table>
<thead>
<tr>
<th>Index No:</th>
<th>Date</th>
<th>Depth at deepest point (m Local Datum)</th>
<th>pH</th>
<th>Salinity (ppt)</th>
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</thead>
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APPENDIX 2

Biological Monitoring – NRHP / AusRivAS Protocols

“Snap-shot” studies of water quality parameters often generate spurious information regarding levels of pollutants. This is particularly relevant to point sources, as concentrations on any particular date may not be representative of the overall input into a system. Similarly, monitoring concentrations alone may sometimes provide misleading information concerning overall loads into a system. Because of this, biological monitoring often proves a more effective tool. Biological methods of water quality assessment (e.g. using communities of fish and macroinvertebrates) are well established throughout the world. Aquatic fauna is constantly sampling water quality and is therefore exposed to peaks and troughs of a pollutant that may be missed by water sampling alone.

The use of fish in biological monitoring (biomonitring) in the south-west of Western Australia is considered to have limited application. In the south-west, the fish fauna is generally depauperate (e.g. low in biodiversity / species richness) (Pusey et al. 1989) and therefore, utilising changes in community structure of fish has a limited applicability. However, given the depauperate nature of the fish fauna, the presence of any native species may confer a level of conservation significance.

The macroinvertebrate fauna of south-western Australia is considered depauperate in worldwide terms (Bunn & Davies 1990). However, as in excess of 200 species commonly occur in south-west forested streams, the fauna is a valuable monitoring tool.

Traditionally, monitoring programs have involved taking replicate samples at a location to produce quantitative data on the abundance of each species of macroinvertebrate. Changes in the abundance of species may then be used to assess the extent of impacts. The criticism of this approach has been that it is typically slow and expensive (viz. many large samples need to be collected, sorted and then identified typically requiring highly qualified taxonomic expertise) to be widely utilised and to quickly provide answers (e.g. to determine whether there has been an “impact”). To overcome this criticism, under the auspices of the National River Health Programme (NRHP) and the Monitoring River Health Initiative (MRHI), the Commonwealth Government has funded over the last seven years the development of Rapid BioAssessment (RBA) protocols and RIVPACS-type models (now named Australian River Assessment Scheme, AusRivAS, models). A summary of the rationale and details of these techniques is presented in Box 1.

The basis of the methodology is the established strong inter-dependence between macroinvertebrate community structure and water quality (and therefore environmental health) at a site. At an undisturbed reference site, it is possible to predict macroinvertebrate community structure based on the physico-chemical conditions. Once these conditions have been changed (e.g. a decrease in water quality due to a point-source discharge), macroinvertebrate community structure will also change. Therefore, by measuring environmental variables that are independent of any possible impacts (i.e. turbidity or pH cannot be used as predictor variables as they may be affected by a pollution event) it is possible to predict the macroinvertebrate community structure that should exist. If the actual macroinvertebrate community as measured by field sampling is different from that predicted, then the site may be determined to be “impacted”.

There are, however, problems associated with AusRivAS monitoring. For example, assessments that rely heavily on family-level data may not detect more subtle changes in community structure occurring at genera or species levels (Edward, Storey & Smith, in press). Live-sorting of samples may underestimate the number of taxa present, in comparison with preserved-sorting.
More importantly, the original Swan Coastal Plain reference sites used in the establishment of the AusRivAS database, were already impacted to some degree, due to widespread environmental disturbances under post-European conditions.

Ideally, AusRivAS modelling should allow assessment against pristine sites, rather than other impacted sites (see Storey 1998). All AusRivAS models are based on pattern detection in macroinvertebrate communities and assume high temporal persistence in the absence of anthropogenic disturbances. While south-west fauna display greater persistence than in many other parts of the country, small year-to-year changes may still occur. In some river systems, therefore, measurement of ecosystem processes (e.g. the sources and fate of energy and nutrients) rather than patterns, may provide a better understanding of the state of river health (Bunn et al. 1999, Bunn & Davies 2000).

Box 1. RIVPACS/AUSRIVAS

The River Invertebrate Prediction and Classification System, RIVPACS, was originally developed in the United Kingdom in the early 1980's by the (then) Freshwater Biological Association (now the Institute for Freshwater Ecology). It has subsequently been expanded and developed with two major revisions of the national UK RIVPACS model (RIVPACS II and III). It is now a major bio-assessment tool used by the National Rivers Authority for performing national assessments of river "quality" at over 8,000 sites in 1995.

RIVPACS is a tool for the comparative assessment of stream ecological "health" based on macroinvertebrate community composition. Development of the RIVPACS models involves a site classification based on macroinvertebrate data (typically presence/absence at species level) collected at "reference" (control) sites (sites that are relatively unimpacted but river types similar to those in which impacts are to be assessed). This is followed by a multiple discriminant function analysis (MDA) of the site groupings using environmental variables. In turn, a model is developed which allows prediction of macroinvertebrate taxa expected to be present at a new site with a given level of probability. Comparison between the expected and observed taxa for a new site are then translated into an assessment of quality using a banding system (i.e. not impacted, mildly impacted, moderately impacted or severely impacted).

For the Australian NRHP, this UK RIVPACS process has been altered to more suit Australian conditions. In the UK, the data base on reference macroinvertebrate sites is derived from rapid assessment sampling (sampling with 1 mm mesh size methods) on 2 - 3 occasions in one year of all habitats at a site. The method includes species identification on preserved samples. The Australian NRHP version involves data collected using rapid assessment sampling (with a 250 μm mesh size) on 2 occasions over 2 years of selected individual habitats (samples maintained separately) with Family level identification on either preserved or live-picked samples. The acronym AusRIVAS (Australian River Assessment Scheme) has been adopted for the Australian versions of the predictive models.

Specific Field & Laboratory Techniques

Macroinvertebrates can be collected from each in-stream habitat (e.g. cobble, riffle, channel, macrophyte) using a 'heel-kick' (Storey et al. 1990) or sweep method (depending on habitat), with a standard 250 μm mesh FBA (Freshwater Biological Association) net with dimensions: 350 by 250 mm opening, 50-75 cm depth and a 1-1.5 m handle. For riffle and channel habitats, the substratum is vigorously disturbed whilst holding the net downstream with its mouth facing the disturbed area and into the stream-flow. The substratum is disturbed by digging the foot into the sediment/stones/gravel and turning them over. Cobbles should be picked-up, turned over and rubbed by hand to dislodge attached organisms into the net.
This process continues upstream over a total distance of about 10 m, covering both the fastest and slowest flowing sections of the specific habitat. Macrophytes are sampled by vigorously sweeping the net within the aquatic vegetation over a length of about 10 m. Sampling should be concentrated in the upper, middle and lower portions of the plants.

All samples, containing sediment, detritus and macroinvertebrate fauna, should be preserved in either 5% formalin or in 70 – 80% ethyl-alcohol, in sealable 2 litre plastic buckets. In the laboratory, samples can then be washed in a flume-hood to remove preservative. Organic sediments, including macroinvertebrates, are then separated from the inorganic material by water elutriation.

The organic sediments are then washed through a series of mesh sieves (e.g. 2 mm, 500 μm and 250 μm mesh sizes) to partition the sample into "large" and "small" fractions. The former can be placed in a white tray and macroinvertebrates removed with the aid of 1.5X magnifying visors. The "small" fractions should be sorted under a binocular microscope at a 6X magnification.

The collected macroinvertebrates should be stored in 70% alcohol and subsequently identified to the lowest possible taxon level (preferably species).
Permits

Fish sampling was conducted under CALM Licence No. SF002850; Date of issue 08/06/1999; Date of Expiry 30/11/1999; Valid from 04/06/1999; Licensee A.W. Storey.

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