APPENDIX A: Environmental Flows Assessment for the lower South Esk River at 'Neck of Bottle'

1. Description of study reach

One of the reaches of the lower South Esk River chosen for environmental flows assessment is located at the 'Neck of Bottle' (TASMAP 5239). This section of the river is situated some 3 km downstream from the historic homestead of 'Clarendon' and about 10 km upstream from DPIW streamflow monitoring station at Perth. This section of the South Esk River has a very low gradient (<0.001), has a moderate degree of meander development (see Plate A1) and in some parts is characterised by the presence of small ox-bow lakes and relict river channels that are connected to the river during high flow events. The lower river consists predominantly of runs and riffles, with pools becoming much less common. Water depth at the centre of the river during the low flows of summer ranges between 0.75-2 m. The river flows through a landscape that is heavily modified by agricultural practices and along much of its length is fringed by crack willow (*Salix fragilis*) and other introduced weeds. Within the river channel itself large sections are inhabited by submerged and emergent aquatic plants (mostly native) and where land has been cleared to the waters edge there are often extensive patches of reed beds that are a favoured habitat of native fish (Plate A2).

Plate A1: Aerial photograph of the lower South Esk River at 'Neck of Bottle'. The blue rectangle indicates the reach where physical form data used for the environmental flow assessment was collected by Davies and Humphries (1996). Photo courtesy of Land Information Systems Tasmania.

The section of river used for the environmental flows assessment encompassed a reach covering 430 m which included a pool (located at the upper third of the reach) and a long run. Elevation, hydraulic and biological data from this reach was collected in the mid-1990's during one of Tasmania's first environmental flows assessments (Davies and Humphries, 1996). Although the data from that study was collected for use in a different assessment methodology, the data has been re-worked for use in the 'Tasmanian Environmental Flows Framework' method now being used by DPIW (DPIW, 2007).

Plate A2: Photo of a long broadwater at 'Clarendon' homestead on the lower South Esk River. While these large pools are most common as the river system emerges from the Fingal Valley, they are less dominant in the lower reaches. The picture shows the extensive thickets of introduced willows that dominate the riparian zone. Where these are not present, the shallower water along the edge of the river contains stands of reeds and aquatic plant beds that contain a diversity of plant and animal species.

2. Environmental Values and Objectives

Although the CFEV database indicates that the lower river system of the South Esk has a low degree of 'naturalness' (CFEV 2005), the reach of river encompassed by this assessment lies within a section that has been defined as having 'medium' to 'very high' conservation management priority*. According to the CFEV database this is generally a result of the remnant vegetation communities that are present alongside the river and the assemblage of fish that is likely to inhabit the river (see relevant chapter in the main document). There are also a number of special values that relate specifically to the aquatic ecosystem, namely:

- Endemic caddisfly species
- South Esk freshwater mussel *(Velesunio moretonicus*)
- High priority riparian and aquatic plant species (*Poa* grassland and Purple loosestrife)
- Platypus (*Ornithorynchus anatinus*)

As well as these, other important biophysical classes that are highlighted within CFEV relate to the geomorphology of the river system, the species of freshwater crayfish (*Astacopsis franklinii*) that occur within the region and the characteristic fringing aquatic plant communities that occur in the South Esk and Macquarie river systems. All of the information obtained from the CFEV database and used to develop environmental objectives for the reach are presented and discussed within the broader context of the South Esk catchment in Chapter 2 of the main report.

* for a definition of these words or terms, see the Glossary in the main report.

Summarised in simple terms, an environmental flow for the lower reaches of the South Esk River should aim to provide sufficient water to meet the needs of;

- the fish community occurring in the river (particularly native fish),
- aquatic and riparian plant communities within the river corridor,
- endemic freshwater biota,
- riverine productivity and basic foodweb structure, and
- geomorphic processes that maintain instream habitat.

Based on this information, Table A1 presents the main environmental objectives that an environmental flow should address and the flow components that are required to achieve the objectives. Further information about these flow components, such as their frequency, timing and magnitude, are provided in Chapter 2 of the main report; that report also provides references to the published literature that illustrate the importance of these flow components in riverine ecosystems. These are similar to those that have been developed for other study reaches in the middle and lower river system (Ormley and Glen Esk), as all of these reaches have some values and characteristics in common.

Table A1 clearly shows that environmental flow provisions for this section of the river should not simply focus on providing a 'minimum flow' during the dry months, but requires adequate provision of water over the entire flow regime. However, prior to undertaking the environmental flow assessment, some analysis of the impact of current water use on the flow regime is necessary. This topic is briefly covered in the next section.

Table A1: Environmental objectives of the environmental flows assessment for the South Esk River at 'Neck of Bottle', and important components of the flow regime that support the objectives

Environmental objectives for the South Esk River at 'Neck of Bottle'	Some of the flow components that are important* in maintaining the environmental objectives and their scientific basis
Maintain healthy populations of native fish	• Seasonal occurrence and magnitude of freshes and minor flood events that act as triggers for migration and dispersal • Baseflows that provide riverine connectivity during summer • High flow events that flush out fine sediments and rejuvenate and maintain spawning habitats
Maintain existing macroinvertebrate community diversity and abundance	• Seasonal pattern of change in baseflow and flow variability; frequency and occurrence of freshes and high flow events to maintain mechanisms of 'drift' and dispersal. • Bankfull and overbank flows during winter and spring to maintain riparian vegetation as sites for breeding and oviposition, and source of instream wood and leaf-packs for food and habitat • Minimum flows to support adequate instream habitat and maintain wetted leaf-packs during dry months
Provide habitat of good quality for instream biota	• Summer and autumn freshes to control unpalatable and habitat-smothering filamentous algae • Flood events that import and move large woody debris, maintain bank undercuts, redistribute fine organic matter and flush fine sediments from riffle macropores • Minimise the duration of extreme low-flow events that may impact on the habitat of endemic freshwater mussels
Maintain healthy instream macrophyte communities and current spatial coverage & distribution	• Maintain wetting/drying regime in shallow, fringing lateral benches and small riparian wetland patches • Maintain seasonal flushes that prevent excessive and prolonged smothering by epiphytic algae
Maintain productivity and benthic metabolism of riverine ecosystem	• Water level in pools and runs that maintain hydraulic head above riffle zones and sustain flow through interstitial pores • Seasonal flow events that flush out attached algae, mobilise bed material and re-set biofilms
Maintain populations of platypus	• Summer low-flows and winter high flows for foraging and maintenance of leaf-packs • Flows that maintain riparian habitat that is suitable for burrows
Sustain existing riparian and floodplain vegetation	• Bankfull flows and larger flood events to recharge local groundwater system and provide access to groundwater during dry periods • Freshes and floods to stimulate re-generation through disturbance, disperse seeds and aid recruitment
Maintain current geomorphic character and processes	• Flood events that mobilise varying size-fractions of bed material, create 'new' patches of instream habitat and physical features and maintain scouring and transport processes • Overbank flow events that maintain larger-scale floodplain features and processes

*For a more detailed list and explanatory text, see Chapter 2 of the main report.

3. Impact of current water use on flows

A risk assessment has been carried out in the main report based (Chapter 4). This was based on an analysis of the alteration in hydrology that has occurred as a result of water use in the South Esk catchment along with a conceptual understanding of the river system. The hydrological analysis of the river at 'Neck of Bottle' (summarised in Chapter 3 of the main report) shows that the main impact of water use has been on the low-flows, where summer abstraction appears to have resulted in lower than natural baseflows. Moderate and high flows are essentially unmodified. Subsequently, the following environmental flow assessment should focus on both providing information on what might constitute an environmentally appropriate minimum flow as well as flood-flow provisions that are likely to maintain the identified environmental values. Given that the current level of water abstraction in this sub-region poses minimal risk to existing environmental values, the recommendations made in the following sections are aimed at preserving these values in the face of potential future increases in water demand.

4. Minimum flow analysis

Chapter 5 of the main report provides details about the methods used to conduct this assessment and the analytical approach used to derive the environmental flow recommendations. The minimum flows assessment is primarily intended to provide water for instream flora and fauna and maintain environmental function during drier periods of the year. To do this, information on the channel morphology and habitat preferences of instream biota are used as input to a hydraulic-habitat modelling procedure.

No topographical or biological information was collected from this reach of the South Esk River during this study. Aside from fish community information collected during recent surveys in the upper river system, the majority of biological and all of the channel survey data that was used for this assessment was taken from earlier work conducted at this reach during early 1990's as part of a minimum flow assessment project (Davies & Humphries, 1996). This early project, which was jointly funded by the National Landcare Program, the Federal Water Resources Assistance Program and the Department of Primary Industries and Fisheries, was the first study in Tasmania to examine minimum flow requirements of Tasmanian rivers. The study examined reaches in the Macquarie, Meander and South Esk rivers. Although this early study used a different approach to the determination of minimum flows for these rivers, much of the data that was collected was re-structured for use in the present assessment, including the habitat-flow relationships that were developed.

Because the earlier study was focused solely on the provision of minimum flows for these rivers, the transect data that was collected did not always extend very far up the river bank. As a consequence, the present study cannot model hydraulic conditions, and therefore predict water levels, when flows at this reach exceed about 15 $m^3.s^{-1}$.

For an assessment of the minimum flow requirements for the 'Neck of Bottle' reach, habitat-use information (primarily depth and velocity preferences) for the following main components of the aquatic fauna were used:

- Native and introduced fish species (Galaxias, blackfish, short-finned eels, and brown trout),
- General abundance of macroinvertebrates,
- The South Esk freshwater mussel *Velesunio moretonicus*,
- The freshwater crayfish (*Astacopsis franklinii*), and
- Platypus (*Ornithorynchus anatinus*)

Because each of these components of the faunal community have different habitat and flow preferences, and therefore different habitat-use curves, an attempt was made to combine the curves for each to provide an estimate of habitat availability with changes in flow for the assemblage as a whole. However it was found that fauna that live predominantly above the bed of the river and are more mobile (fish, crayfish and platypus) tend to prefer water depth and velocity conditions that occur under lower flows. In contrast, the less mobile fauna (macroinvertebrates*) were generally more tolerant of greater water depths and velocities. In developing recommendations for minimum environmental flows for the Neck of Bottle, it was therefore decided to examine the habitat-use information of these two different suites of fauna separately.

The habitat-use curves for fish, crayfish and platypus were combined to form a 'mobile' fauna assemblage curve (Figure A1). This habitat-use curve includes the habitat preferences for adult and juvenile brown trout (*S. trutta*). Although brown trout are an introduced species, the exclusion of this species did not significantly alter the shape or size of the rating curve. However it was found that the curve was disproportionately affected by the inclusion of the habitat preferences of pygmy perch (*Nannoperca australis*), which is generally restricted to the shallow water and very low velocity environment that is provided by aquatic plant habitats that fringe the broadwaters of the river. As this habitat is not present in any significant amount at the Neck of Bottle reach, the habitat preference information for this species was not included in the mobile fauna assemblage curve.

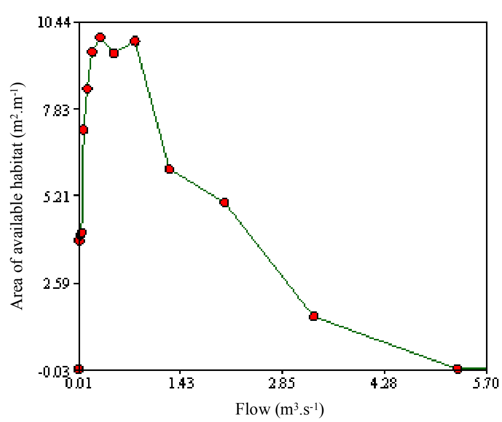

Figure A1: The 'mobile fauna' assemblage habitat-use curve for the 'Neck of Bottle' reach on lower South Esk River. This rating curve shows how the area of available habitat for this assemblage as a whole (in units of square metres per metre of river length), varies with changes in flow. The curve is derived from the amalgamated information on habitat preferences for most native and introduced fish, crayfish and platypus.

* for a definition of these words or terms, see the Glossary in the main report.

The curve shows that the greatest amount of area available for this assemblage (shown on the y-axis in units of square metres of habitat area per metre of river length) is present at flows between about 0.15 and 1.2 $m^3.s^{-1}$. The maximum amount of habitat (9.75 $m^2.m^{-1}$) occurs at a flow of 0.25 $m^3.s^{-1}$.

The habitat-use curves for freshwater mussels and macroinvertebrate abundance have been combined to produce a 'benthic' fauna assemblage habitat-use curve (Figure A2). The curve shows that the habitat for this community increases rapidly between zero and about 5 $m^3.s^{-1}$, after which habitat availability begins to reach a plateau. Peak habitat for this assemblage is likely to exceed 28 $m^2.m^{-1}$ at flows in excess of 14 $m^3.s^{-1}$, but cannot be predicted because the hydraulic model only operates up to that level. As has been found in other study reaches in the South Esk catchment, this assemblage clearly benefits from the increased water depth and higher velocities that occur at higher flows.

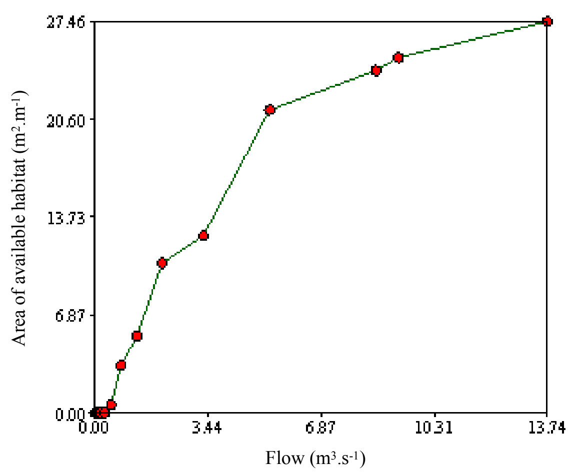

Figure A2: The 'benthic fauna' assemblage habitat-use curve for the 'Neck of Bottle' reach on lower South Esk River. This rating curve shows how the area of available habitat for this assemblage as a whole (in units of square metres per metre of river length), varies with changes in flow. The curve is derived from the amalgamated information on habitat preferences for the South Esk freshwater mussel (*V. moretonicus*) and general macroinvertebrate abundance.

Using each of these rating curves, time series of habitat availability were generated from the 'natural' flow record for the South Esk River at this location. The 'natural' flow data was generated from the hydrological model that has been developed for the South Esk catchment under the NAP program. For this study, 43 years of daily average flow data was used as this is the period that has the best record of rainfall and evaporation data on which predictions of flow can be made.

Because this component of the assessment is focused on the low-flow aspect of the water regime, a procedure called 'baseflow separation' was performed (using the Lyn-Hollick filter for digital baseflow separation, with an alpha-value of 0.95). The resulting baseflow time series was then used to generate a time series of changes in available habitat within the river using the rating curves shown above. Some of these results are shown in Figure A3, which compares changes in habitat availability for mobile and benthic fauna assemblages with changes in daily average baseflow. From this graph the preference of the 'mobile' fauna assemblage for low flows is apparent.

As streamflow drops below 5 $m^3.s^{-1}$ (432 $Ml.day^{-1}$), the availability of preferred habitat increases. Although the habitat-use time series for this assemblage implies that habitat availability falls near to zero at times of high flow, during these periods the species contributing to this curve will actually seek refuge in low-velocity areas such as within snag piles, behind large boulders and (for crayfish) within the bed of the river. So, while the amount of preferred habitat may be reduced during higher flows, refuge habitat will always be available as long as the structure of the river remains in a near-natural condition.

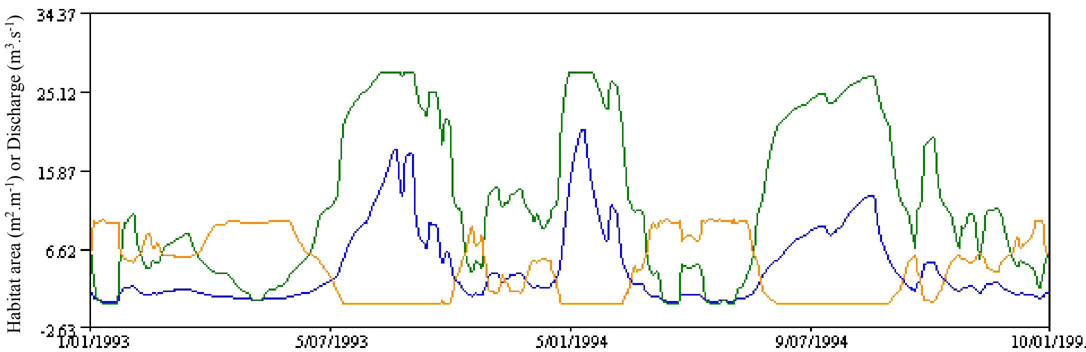

Figure A3: Time series of changes in the availability of preferred habitat for 'benthic fauna' (red line) and 'mobile fauna' (green line) alongside changes in 'natural' baseflow (blue line) at 'Neck of Bottle' in the lower South Esk River between Jan 1993 and Jan 1995. Habitat availability is plotted as m^2 per metre of river length and flow is plotted as cumec ($m^3.s^{-1}$). Habitat availability for 'benthic fauna' is maintained at a maximum of 28 $m^2.m^{-1}$ at flows greater than 14 $m^3.s^{-1}$ because of model limitations that do not permit habitat to be predicted at flows above this level. For 'mobile fauna', habitat values drop to zero at flows above 5 $m^3.s^{-1}$ as increased velocity creates less favourable conditions for native fish. See text for more detailed explanation.

The data that produces this graph can be summarised and plotted in the form of a chart showing the average amount of habitat available on a monthly time-step (Figure A4). It shows that the highest proportion of preferred instream habitat is available for the mobile fauna assemblage during baseflows that occur between December and April, and that higher baseflows naturally cause a reduction in habitat availability during the months of July to October. As noted above, this is mainly an artefact of the modelling process, which is focussed on habitat preferences during lower flow conditions, and does not recognise that these fauna are able to seek alternative habitat as refuge during unfavourable flow conditions.

In contrast, the monthly change in habitat under baseflows for the benthic fauna assemblage shows that the highest proportion of preferred instream habitat is available during the period July to October and that during the late summer and autumn months, habitat availability is much more limited.

From this comparison it is clear that during the dry months of December to April, when average baseflow falls below 5 $m^3.s^{-1}$, habitat for benthic fauna is reduced. It should also be recognised that unlike the species in the mobile fauna assemblage, during these times the benthic fauna are less able to move out of areas that are drying out and take refuge in the remnant pools. It is therefore appropriate that during the dry months the minimum flow recommendations are aimed at providing adequate habitat for the benthic fauna assemblage.

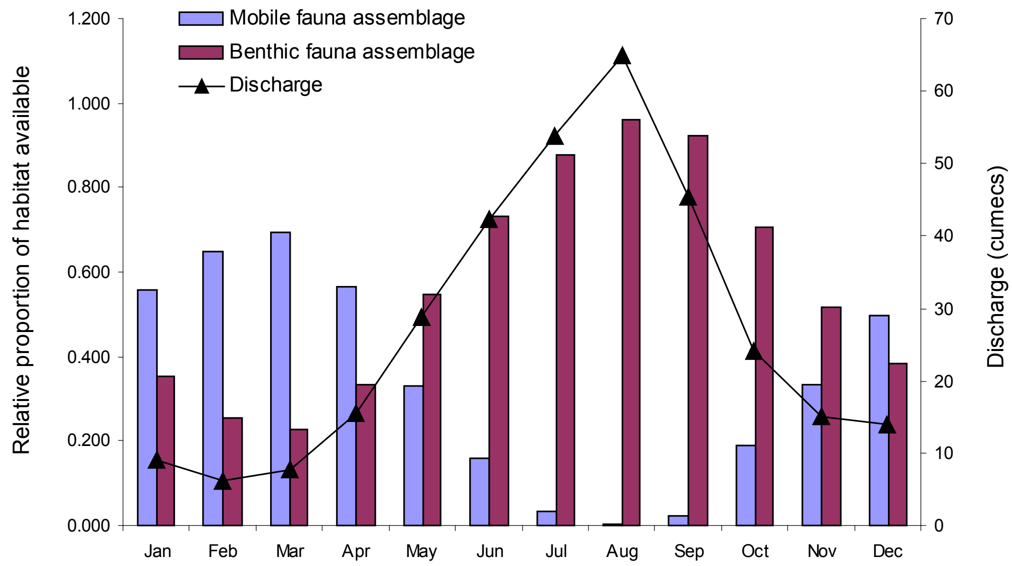

Figure A4: Graph showing the average proportion of baseflow stream area available as preferred habitat for 'benthic fauna' and 'mobile fauna' (bars) alongside changes in monthly average 'natural' flow (line) in the lower South Esk River at 'Neck of Bottle'. The proportion of habitat available is a function of the area that is actually available under average monthly baseflow relative to the maximum area this is available at the preferred flow.

To determine the minimum flow level, the time series of habitat area available for benthic fauna (derived from the conversion of the 43-year modelled record for 'natural' baseflows), was statistically analysed. The daily data for each month was aggregated and from these subsets of data percentiles of habitat availability were computed. The outcome of this analysis is graphically presented in Figure A5. It shows the monthly change in selected percentiles of habitat area available for benthic fauna. From the graph it is clear that there is a significant decline in habitat availability for benthic fauna during February and March, and that the 50th percentile throughout the summer months is at or near to 5 $m^2.m^{-1}$. This is less than one fifth of what is available during most of the winter months.

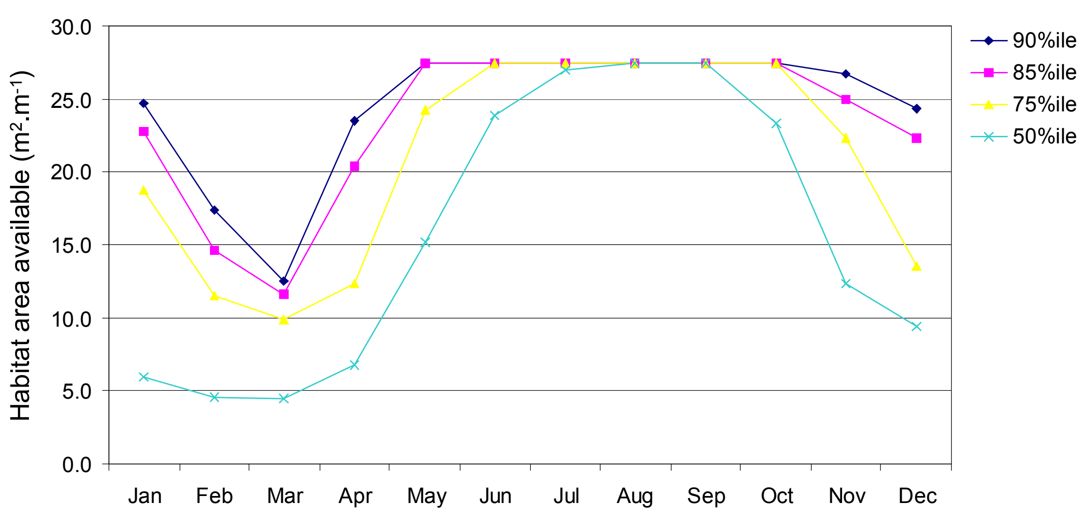

Figure A5: Graph showing the monthly change in selected percentiles of habitat area available for the 'benthic' fauna assemblage in the South Esk River at the 'Neck of Bottle' using modelled 'natural' baseflows from 1960 to 2003.

Table A2 provides an indication of the flows (as daily average flow) that maintains 85%, 75% and 50% of habitat for 'benthic fauna' within the river. Knowing what flows will provide what percentage of instream habitat for benthic fauna provides a good basis for making recommendations for minimum environmental water provisions. This recognises that the benthic fauna assemblage is the component of the aquatic community that is most likely to be limited by low flow conditions.

Table A2: Monthly 85th, 75th and 50th percentiles of instream habitat for 'benthic fauna' at the Neck of Bottle study reach derived from 'natural' baseflow data, and the corresponding flow that provides these amounts of habitat.

MONTH	85%ile habitat ($m^2.m^{-1}$)	Flow that maintains 85% of habitat ($m^3.s^{-1}$)	75%ile habitat ($m^2.m^{-1}$)	Flow that maintains 75% of habitat ($m^3.s^{-1}$)	50%ile habitat ($m^2.m^{-1}$)	Flow that maintains 50% of habitat ($m^3.s^{-1}$)
Jan	22.80	7.11	18.73	4.73	5.91	1.36
Feb	14.68	3.81	11.52	2.70	4.56	1.09
Mar	11.62	2.78	9.84	1.94	4.50	1.08
Apr	20.40	5.10	12.381	3.28	6.73	1.48
May	27.42	13.66	24.27	8.74	15.19	3.91
Jun	27.46	13.70	27.46	13.70	23.91	8.40
Jul	27.46	13.70	27.46	13.70	27.02	12.90
Aug	27.46	13.70	27.46	13.70	27.46	13.70
Sep	27.46	13.70	27.46	13.70	27.46	13.70
Oct	27.46	13.70	27.46	13.70	23.30	7.69
Nov	24.95	9.27	22.29	6.56	12.31	3.21
Dec	22.30	6.53	13.55	3.55	9.39	1.88

In developing a minimum flow recommendation for this reach of the river, consideration must also be made of flows that maintain connectivity between pools during dry periods. Examination of the hydraulic transect data from the current hydraulic model for the reach suggests that ≥ 0.35 $m^3.s^{-1}$ (30 $ML.day^{-1}$) is needed to maintain connectivity throughout the reach. The model shows this flow maintains ≥ 0.1 m depth throughout the entire reach, in particular the areas where the shallow runs occur.

4.1 Recommendations for minimum flow provisions

While the data in Table A2 provides useful information on what amount of instream habitat is available under different low flow conditions, using this information to make recommendations regarding minimum flow allocations requires some discussion of ecological consequences.

The 'habitat availability' values in Table A2 were calculated using baseflow data that were extracted from the 'natural' flow data provided by the hydrological model for the catchment. These baseflow data do not contain flow variability that is associated with surface runoff and represent minimum flows that would occur in the absence of agricultural water extraction. These data can therefore be considered as providing a 'reference' condition.

Given the method used to generate the habitat availability data, it is clear that adopting a minimum flow that aims to maintain 85% of instream habitat (the 85% habitat maintenance flow) is the most conservative alternative and likely to provide the best protection for instream ecosystem values. At the other extreme, adopting a minimum flow level that will maintain only 50% of instream habitat is less likely to sustain a healthy and productive aquatic ecosystem. Although the rating curve for the mobile fauna shows that these flows will provide more suitable habitat for that assemblage, in particular native fish species, flows of this magnitude (1-1.5 $m^3.s^{-1}$) are less likely to provide sufficient habitat to maintain invertebrate abundance and diversity.

Furthermore, the rationale for adopting a 'median condition' has been used in other environmental flow studies where researchers have sought to establish a 'standard' or 'reference' condition. Adopting a median value recognises environmental variation, and the balance between extreme stress and abundant provision. Whilst adopting a median is less conservative than adopting an 85^{th} percentile, if it is considered as an 'absolute limit' (i.e. as a cease-to-take flow) then it should restrict the temporal extent of flow-related 'stress' to the aquatic ecosystem. Adopting the 50% habitat maintenance flow as a 'cease-to-take' limit means that while the ecosystem will continue to be exposed to periodic 'acute stress' during periods of extreme low-flows, it should limit the risk of 'chronic stress' associated with prolonged and frequent exposure to these conditions.

On this basis, an environmental flow that maintains 75% of instream habitat for the benthic fauna at the South Esk River at the 'Neck of Bottle' is recommended, and that this be provided on a monthly basis to ensure that seasonal changes in baseflow are preserved. This level of flow should be adopted as the 'sustainable limit' for water allocation, as any allocation of water beyond this is likely to lead to an increased risk of 'chronic' flow-related stress to the aquatic ecosystem. For daily management of water use, the 50% habitat maintenance flow is recommended as providing an appropriate 'cease-to-take' flow. The monthly flows that correspond to these levels are provided in Table A3.

The main focus of this recommendation is on the provision of minimum flows during the irrigation season (October to April) when the extraction of water directly from the river is of greatest concern. During the months outside of this period, water allocation is focussed on the capture of floodwater for on-farm storage, so the minimum flow values for these months may not apply but are provided nevertheless.

Table A3: Recommended environmental flows and 'cease-to-take' flows for the South Esk River at the 'Neck of Bottle'.

MONTH	Environmental Flow (75% habitat maintenance flow) ($m^3.s^{-1}$)	Cease-To-Take Flow (50% habitat maintenance flow) ($m^3.s^{-1}$)
Jan	4.73	1.36
Feb	2.70	1.09
Mar	1.94	1.08
Apr	3.28	1.48
May	8.74	3.91
Jun	13.70	8.40
Jul	13.70	12.90
Aug	13.70	13.70
Sep	13.70	13.70
Oct	13.70	7.69
Nov	6.56	3.21
Dec	3.55	1.88

In developing water management measures for the Lower Esk sub-region, the Water Management Plan should also consider the monthly minimum flow recommendations for the reach at 'Glen Esk', where the recommended flow provisions have also taken into account the water needs of fringing macrophyte beds. This ecosystem feature is largely absent from the 'Neck of Bottle' reach, but is present throughout much of the lower South Esk river system and is an important environmental value.

5. Flood flow analysis

In contrast to low-flows, 'flood flows' or 'high flows' comprise the majority of the variability in the flow regime of a river. Flow events from this part of the hydrograph include small 'freshes' created by brief rainfall events, larger 'channel maintenance' events that occur 5-10 times per year, and floodplain inundation events that are commonly perceived as 'major floods' in the landscape. Each of these flow events are important in creating and maintaining the form and character of the river (Gippel, 2001), as well as creating a diversity of hydraulic environments that supports aquatic biodiversity (see discussion in Biggs *et. al*., 2005; and Thoms, 2006). It is important, therefore, that in making judgements about the flow regime that is required to sustain river ecosystems, some consideration is made of the characteristics (eg. timing, frequency, magnitude, rate of rise and fall) of these events. To do this, a method called 'high spells' analysis has been used (Marsh *et al.,* 2003).

5.1 High Spells Analysis

High spells analyses, using the RAP software package, were used to examine the nature and timing of flow pulses, which tend to occur several times per year and are not normally considered to be major flow events. This technique involves setting flow thresholds (that are of ecological and/or geomorphological importance) and analysing flow time series' to determine statistics such as their frequency, timing, and duration. Bank-full discharge is one useful threshold for analysis as it is often assumed to control the form of alluvial channels (Gordon, *et. al,* 2004), and is considered to have an important role in 'channel maintenance' and the transport of sediment (Newbury and Gaboury, 1993; Gippel, 2001).

Because the transect data that was used for this site was taken from prior studies that were focussed on the assessment minimum flow requirements for the river (as discussed earlier), a desktop estimate of what flow results in bank-full discharge could not be made. From the baseflow separation analysis it is known that baseflow during the winter peaks at about 12 $m^3.s^{-1}$ at this location. At reaches upstream, where topographic surveys extended further up the river bank, bank-full discharge was estimated to be about 3-4 times peak winter baseflow, so for this reach a similar level has been used to approximate bank-full flow. This translates to about 40 $m^3.s^{-1}$ at the 'Neck of Bottle' reach.

Two additional high spells analyses were conducted using the 5% exceedance[*] and 20% exceedance flows as thresholds. For these analyses, events were defined as those that last for ≥1 day and were classed as independent if there were at least 5 days between the peaks in associated flow events. Natural flow data from the hydrologic model for the South Esk catchment were used as input in these analyses; data from this model are at a daily time-step as 'daily average flow'.

The 5% exceedance flow threshold (105 $m^3.s^{-1}$) has been used to represent over-bank flow events that are also likely to create channel scouring and sediment transport velocities. The 20% exceedance flow (32 $m^3.s^{-1}$) was used to examine the seasonal frequency and duration of small events that could be classified as 'freshes' or

[*] for a definition of these words or terms, see the Glossary in the main report.

'flushing' flows. In addition to its ecological relevance, the 20% exceedance value was also chosen as it approximates the level of the 'flood harvesting rule' developed by Hydro Tasmania; this is applied at the Llewellyn streamflow monitoring station in the lower catchment. Under this management rule, additional agricultural abstraction can occur for a 5-day period once flow at Llewellyn exceeds 20-23 $m^3.s^{-1}$ (depending on the season).

Table A4 below, provides both an annual summary as well as a seasonal break-down of the results of these analyses. For both the estimated bank-full flow threshold and the 5% exceedance flow threshold, events are more frequent in winter and spring and fewer in summer. The duration of bank-full events is almost twice as long in winter than summer, however the results for the 5% exceedance flow threshold indicate that large events that occasionally occur in summer and autumn tend to have average durations that are comparable to those that occur in winter. These figures reflect the influence of intense rainfall events that are generated by low-pressure systems that tend to develop off the northeast coast of Tasmania in autumn and last for periods of up to a week.

Events with a 20% exceedance flow threshold occur, on average, about 8 times per year and have an average duration of about 10 days, while events that over-top the river banks and flood the riparian zone and floodplain (5% exceedance events), occur on average about 4 times per year and last only half as long.

The data in Table A5 show the average duration and rates of rise and fall in the hydrograph for the river at Neck of Bottle. It provides additional information on rates of change in flow that occur, and illustrates that the river responds rapidly to runoff, with shorter durations (and larger rates) of rise in flows in comparison to falls. Whilst these figures are informative, they are most valuable when viewed in conjunction with figures derived for other locations in the river system. It must also be remembered that they have been derived using *daily* time series data, which is the shortest time-step available from the hydrological model for the catchment.

Table A4: Summary of high spells analysis using the 'natural' flow data for the South Esk River at the 'Neck of Bottle'. The 20% exceedance threshold (32 $m^3.s^{-1}$) approximates minor 'freshes' or 'flushing' events at this reach, the second threshold (40 $m^3.s^{-1}$) corresponds approximately with 'bank-full' discharge, and the 5% exceedance threshold (105 $m^3.s^{-1}$) approximates over-bank floods.

	20% exceedence (32 $m^3.s^{-1}$ or 2,765 $ML.day^{-1}$)			Bank-full flow threshold (40 $m^3.s^{-1}$ or 3,450 $ML.day^{-1}$)			5% exceedence (105 $m^3.s^{-1}$ or 9,070 $ML.day^{-1}$)		
	Average frequency	Average duration (days)	Average magnitude ($m^3.s^{-1}$)	Average frequency	Average duration (days)	Average magnitude ($m^3.s^{-1}$)	Average frequency	Average duration (days)	Average magnitude ($m^3.s^{-1}$)
Annual	7.9	10.3	147	7.6	8.4	158	3.8	4.8	266
Spring	2.5	9.5	120	2.2	7.2	128	1.0	3.5	191
Summer	0.7	6.1	123	0.6	5.0	127	0.2	4.6	266
Autumn	1.4	7.2	168	1.3	6.2	186	0.5	5.6	380
Winter	3.9	11.6	170	3.9	9.3	171	2.1	4.8	260

Table A5: Average duration of rise and fall in flow and rates of change in flow, for the South Esk River at 'Neck of Bottle'.

Statistic	South Esk River at 'Glen Esk'
Mean duration of Rises	3.8
Mean rate of Rise	11.2
Mean duration of Falls	9.9
Mean rate of Fall	6.8

Understanding the size and duration of ecosystem-relevant flow pulses, it is worth re-examining these thresholds in relation to inter-annual changes in hydrology. This has been done in Figure A6, where the hydrograph for the years 1995 and 2000 are plotted alongside the two flow thresholds. This figure highlights the variations between years in the timing and frequency of events. In 1995 (which was the drier year), only 1 event exceeded the 5% exceedance threshold of 105 $m^3.s^{-1}$ and this occurred in the middle of winter. During 2000, when the overall yield from the catchment was substantially higher, this threshold was exceeded 3 times and nearly reached on an additional two occasions.

Another feature of the figure is the presence of large events that occur in summer of both 1995 and 2000. Both of these illustrate the runoff that can occur during large events that occur in late summer or autumn.

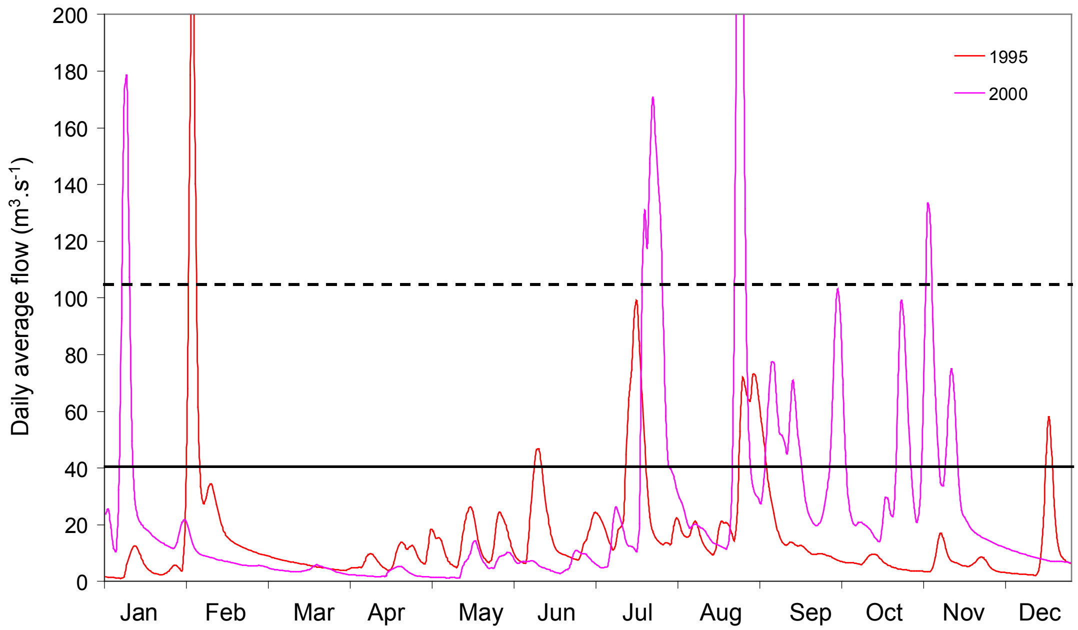

Figure A6: Graph comparing daily average 'natural' flow at Neck of Bottle on the South Esk River during 1995 and 2000, along with the two flow thresholds used for high spells analysis.

Given that the current availability of water during the summer is limited, and extraction of water from the South Esk system is being encouraged during the winter period, these high spells analyses provide a basis from which to make recommendations regarding 'environmentally sustainable' allocation of flood water. it is fundamental that as far as practicable, the natural flow regime of the river should be maintained. One of the main objectives of the Tasmanian Environmental Flows Framework is to maintain, as far as practicable, the natural pattern of flows. The main environmental and ecological reasons for this are that flooding: provides numerous environmental benefits in terms of nutrient and sediment dispersal, acts to maintain the river form and character, distributes wood and organic material upon which instream fauna rely, and rejuvenates riparian vegetation communities. Bearing these various roles in mind, the following recommendation is made.

5.2 Recommendations for allocation of flood water

It is recommended that the allocation of floodwater be restricted to times when flow at Neck of Bottle exceeds 40 $m^3.s^{-1}$. Extraction of flood water during this time should not significantly affect flood duration and to ensure this we recommend that 650 $ML.day^{-1}$ be made available for extraction for up to 5 days once 40 $m^3.s^{-1}$ is exceeded or until flow falls below the threshold. This volume of water represents about one fifth of the bank-full flow threshold, and is considered to be relatively conservative in terms of protecting the shape of high-flow events and the natural pattern of the flow regime. Considering that events exceeding 35 $m^3.s^{-1}$ occur on average about 8 times per year, this makes about 26,000 ML potentially available on an annual basis. No seasonal boundaries to this rule are proposed.

Under the recommended flood harvesting rules outlined above, all flow events occurring below the 35 $m^3.s^{-1}$ flow threshold are protected. The ecological value of these smaller events is particularly important during prolonged periods of low-flow, as they provide some variability when conditions have been static, and have been viewed as having a role in 'relieving stress' on the system (Poff, *et al.*, 1997; Webster, *et al*., 2000). In a dry year (such as 1995 shown in Figure A6 above) these events may constitute a relatively higher proportion of the variability in the flow regime. These events are also the part of the flow regime that are most impacted by the proliferation of catchment dams. In the case of the South Esk catchment, these events are presently provided some measure of protection by flood harvesting rules (discussed above) that were instituted by Hydro Tasmania following their South Esk Water Management Review in 2003. Under this rule the combined flow at monitoring sites on the Meander Macquarie and South Esk rivers must exceed 70 $m^3.s^{-1}$ before flood water can be extracted from any of the 3 river systems.

It should also be recognised that the recommendation made here needs to be considered in the light of similar recommendations made for locations upstream and down the South Esk River system. Any water that is allocated from the catchment above this point needs to be accounted for in downstream management and as part of an overall 'extraction cap' for the catchment.

6. Summary

The environmental values that have been identified for the lower South Esk River system relate to the fish community inhabiting the river, the aquatic and riparian plant communities within the river corridor and the geomorphic character and processes that maintain instream habitat and productivity. In providing environmental flows to maintain these values, the objective has primarily been to retain the natural variability in the flow regime as much as possible. To do this, recommendations have been made regarding monthly minimum flow provisions and extraction rules aimed at preserving the magnitude and duration of high flow events.

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Monthly minimum flows have been recommended with the aim of maintaining sufficient habitat for benthic fauna and the fish community, and these may be incorporated into the Water Management Plan for the catchment in the form of allocation limits and cease-to-take triggers at the streamflow monitoring station at Perth. Although the primary aim has been to assist with the extraction of water during the irrigation period (October to April), data has been provided that covers the rest of the year, and should guide the 'winter' allocation of water.

Basic rules have been recommended regarding the extraction of water during times of flood, and these need to be considered in tandem with rules for water extraction that presently exist as part of Hydro Tasmania's water management process.

It is anticipated that these recommendations will preserve the natural character of the flow regime sufficiently to maintain the freshwater values that have been identified for the lower South Esk River and sustain the ecosystem into the future.