APPENDIX D: Environmental Flows Assessment for the upper South Esk River at 'Malahide'

1. Description of study reach

This site on the upper South Esk River is located on the Malahide property approximately 7 km upstream of the township of Fingal and immediately usptream from Giles Marsh (Figure D1). At this location, the river is relatively small-sized, but has an active channel width of approximately 14-38 m due to frequent high flow events and river incision and widening.

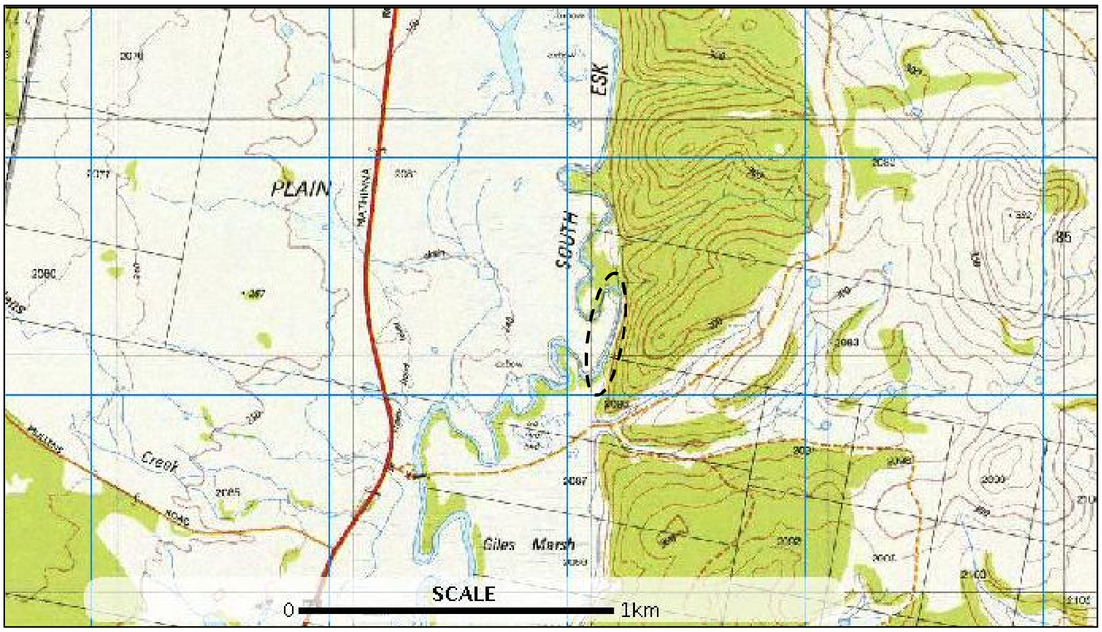

Figure D1: Map showing the location (as indicated by the dashed circle) of the environmental flows study reach immediately upstream of Giles Marsh on the upper South Esk River (base map by theLIST, © State of Tasmania).

This study reach is located in an area that is used for agriculture (grazing and cropping) and forestry operations (plantation timber harvesting) and, hence, it has been substantially modified from its natural condition. The eastern bank of the river is at the base of a small range of hills that run parallel with the river for several kilometres and the western bank of the river forms the boundary to open paddocks that are used for pasture. Whilst many parts of the active river channel are steep and indicate active erosion processes, the riparian zone* on the eastern bank is covered primarily by a mixture of native vegetation including woolly teatree (*Leptospermum lanigerum*), *Eucalyptus* spp., dogwood (*Pomaderris* sp.), silver wattle (*Acacia dealbata*), *Poa* grasses and herbaceous species. However, introduced willows (*Salix* spp.) are also dominant in some parts of the reach (Plates D1 & D2). The southern river bank, and its immediate floodplain, is less vegetated and contains a mixture of native species (mostly woolly teatree and silver wattles) and exotic species such as willows and pasture grasses.

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

Unlike many parts of the middle and lower river system, this reach contains a diversity of instream habitats including snags in the form of woody debris, undercut banks, submerged root mats, leaf packs, submerged macrophytes*, and beds of coarse gravel. During low flows, the river bed in both pools and glides is generally covered by a fine layer of silt.

Plates D1 & D2: Photos of the South Esk River at the Malahide site during low flows showing the mixture of native and exotic vegetation that is found on the river banks. A typical hydraulic jump (which is caused by a fallen log), submerged macrophytes and accumulations of woody debris are also shown.

The river at this location has a complex channel that often divides in two; some of these secondary channels have similar thalweg depths to the primary channel and others appear to only contain water during medium-sized flows. During low flows, the river contains defined pools (depths typically >1.0 m) that are connected by glides and shallow riffles (depths typically <0.5 m). There are also several hydraulic jumps in the bed of the river that have been formed by fallen trees that have embedded into cobble substrate (Plate D2) and restrict local water depth. Water depth over these fallen logs during low flow conditions is generally <0.15 m.

Based on surveys of thalweg* elevation that were conducted across the 265 m length of the study reach, the overall gradient of the river was estimated to be about 0.0012 (or 1.2 m of fall per kilometre of river distance).

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

2. Environmental Values and Objectives

In the CFEV database, the reaches of the South Esk River around the Malahide site have been assessed as having varying degrees of naturalness (i.e. 'low' to 'high') (CFEV 2005); however, this stretch of river has a 'very high' conservation management priority*. According to the CFEV database, the main values that appear to drive the conservation management priority for this part of the river relate to its geomorphology. There are also a number of special values that relate specifically to the aquatic ecosystem in this area, namely:

- High priority riparian flora communities
- Floodplain *Poa* grassland
- Shrubby *Eucalyptus ovata* forest
- Tall quillwort (*Isoetes elatior*)

Additional to these special values, other important biophysical classes are also highlighted in the CFEV database. These relate to: the fish assemblage that inhabits this area of the catchment, the tree assemblage through which the river flows, freshwater crayfish that occur within the region, the unique aquatic plant communities that occur in the upper South Esk River, and aquatic macroinvertebrate* communities. All of the information that was obtained from the CFEV database and used to develop environmental objectives for the reach, is presented and discussed within the broader context of the South Esk catchment in Chapter 2 of the main environmental flows report.

In summary, an environmental flow for the upper South Esk River should aim to provide sufficient water to meet the needs of:

- the fish community occurring in the river (particularly native species),
- endemic freshwater crayfish (*Astacopsis franklinii*),
- platypus (*Ornithorynchus anatinus*),
- riparian plant communities within the river corridor,
- aquatic macroinvertebrate communities,
- riverine productivity and basic foodweb structure, and
- ongoing geomorphic processes.

Based on this information, Table D1 presents the environmental objectives that an environmental flow allocation should address and the flow components that are required to achieve these objectives. Further information about these flow components, such as their frequency, timing and magnitude, are provided in Chapter 2

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

of the main report; that report also provides references to the published literature that illustrate the importance of these flow components in riverine ecosystems.

Table D1: Environmental objectives of the environmental flow assessment for the South Esk River at the Malahide site, and important components of the flow regime that support the objectives.

Environmental objectives for the South Esk River at Malahide	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 low flows • High flow events that flush-out fine sediments and rejuvenate and maintain spawning habitat
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 sources 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 abundance of unpalatable and habitat-smothering filamentous algae • Flood events that import and move large woody debris, maintain bank undercuts, redistribute fine organic matter and flush-out fine sediments from riffle habitats
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 cavities • Seasonal flow events that flush-out attached algae, mobilise bed material and re-set colonisation by 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 aid recruitment by dispersing seeds, and stimulating regeneration through disturbance
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 physical features and processes in floodplains

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

Table D1 clearly shows that environmental flow provisions should not simply focus on providing a 'minimum flow' during the dry months, but rather, they need to provide adequate water across the entire flow regime. However, prior to undertaking the environmental flow assessment, the impact of current water use on the flow regime of the study site should be examined. This topic is briefly covered in the next section.

3. Impact of current water use on flows

A risk assessment has been carried out in the main report by examining the degree to which the hydrological regime in the South Esk catchment has been altered from its natural state as a result of water use (Chapter 4); a conceptual understanding of the river system was also used in these analyses. The hydrological analysis of the Upper Esk sub-region (summarised in Chapter 3 of the main report) shows that the current flow regime is essentially unmodified, and that, presently, water use in the upper catchment impacts only marginally on the low flow component of the flow regime. Subsequently, the following environmental flow assessment for the upper South Esk River system focuses on providing information on what may constitute an environmentally appropriate minimum flow, as well as flood flow provisions that are likely to maintain the identified environmental values. Given that, currently, the 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 even if water use increases in this region in the future.

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. No prior work has been done to assess instream habitat in the upper South Esk River. Therefore, a 'representative reach' of the river at Malahide was selected and surveyed in December 2006 to collect information on channel form and gradient. The discharge at the study reach at the time of the survey was also recorded (0.91 $m^3.s^{-1}$ or 79 $ML.day^{-1}$). In addition, electrofishing was conducted to examine the composition of the fish assemblage inhabiting the river in this area. The species that were either collected or observed were:

- Short-finned eel (*Anguilla australis*)
- Blackfish (*Gadopsis marmoratus*)
- Redfin perch (*Perca fluviatilis*)
- Brown trout (*Salmo trutta*)
- *Galaxias* sp. (unidentified, but likely to be *G. brevipinnis*)

The minimum flow requirements for the South Esk River at this site were assessed by using habitat preference information (i.e. preferred depths and velocities) for fish species that were present, freshwater crayfish (*Astacopsis franklinii*) and platypus. To incorporate the needs of aquatic macroinvertebrates, relationships between the abundance of macroinvertebrate communities and river discharge from other studies in the South Esk River system and elsewhere in Tasmania were also used.

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, this was not possible because of significant differences between the habitat requirements of macroinvertebrates and the mobile taxa (i.e. fishes, crayfish and platypus).

The mobile taxa that live predominantly above the bed of the river tend to prefer water depths and velocities that occur under lower flows. The habitat-use curves for these taxa were combined to form a mobile fauna assemblage curve (Figure D2). This habitat-use curve includes the habitat preferences for adult and juvenile brown trout (*Salmo trutta*). Although brown trout are an introduced species, they are highly valued for recreational angling in this catchment. Furthermore, their inclusion did not greatly alter the rating curve that was derived only for native species. The habitat-use curve that was generated for this assemblage most closely resembles the curve for adult blackfish (*Gadopsis marmoratus*) at this reach, which of all the fish species present has the highest priority in terms of conservation.

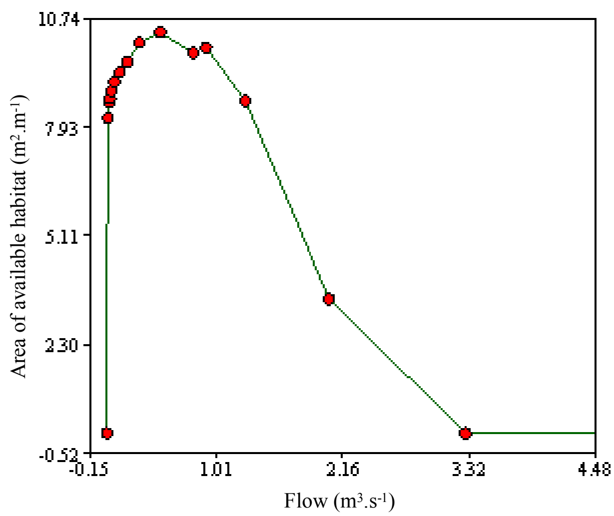

Figure D2: The 'mobile' fauna assemblage habitat-use curve for the South Esk River at the Malahide site. This rating curve, which shows how habitat availability varies with changes in flow, is derived from the amalgamated information on habitat preferences for native and introduced fishes, crayfish and platypus.

Whilst greater amounts of habitat are available for the mobile fauna assemblage at this reach (as indicated by the higher peak values on the y-axes of Figure D2), habitat for macroinvertebrate abundance is available over a much greater range of flows (0.2 to 35 $m^3.s^{-1}$; Figure D3). This assemblage is much less mobile and more reliant on the habitat provided by substrates within the river channel; therefore, it is less affected by the greater water depths and higher velocities that occur during higher flows.

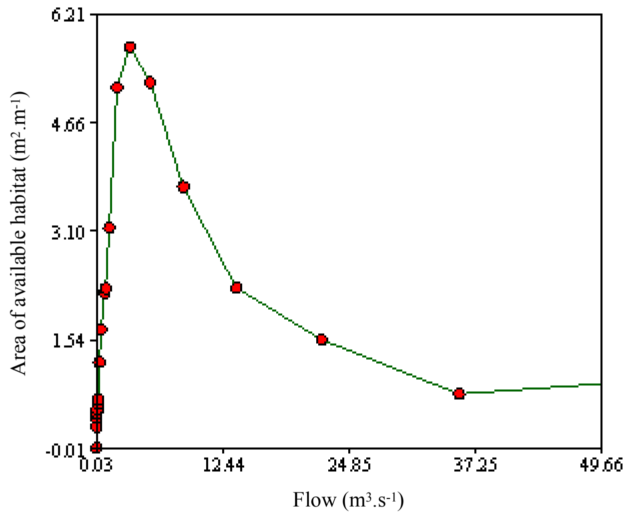

Figure D3: The general invertebrate abundance habitat-availability curve for the South Esk River at the Malahide site. This rating curve shows how habitat availability varies with changes in flow in this reach.

The habitat-use curve for mobile fauna (Figure D2) shows that flows between 0.05 and 1.30 $m^3.s^{-1}$ (4.3 and 112 $ML.day^{-1}$) provide the largest amount of habitat for this assemblage at this site. The maximum amount of habitat available for this assemblage is 10.4 m^2 per metre of river length and this occurs at a flow of 0.50 $m^3.s^{-1}$ (43 $ML.day^{-1}$). These findings are supported by the known habitat preferences of adult blackfish: they use pools where water velocities are low and there is cover provided by snags. Flows between 0.05 and 1.50 $m^3.s^{-1}$ would allow pools to have depths and velocities that provide optimal conditions for habitation by these fish. Higher flows are likely to 'wash-out' these habitats and force the fish to seek refuge in other non-preferred habitats.

Conversely, the habitat-use curve for invertebrate abundance (Figure D3) shows that flows between 1.30 and 10 $m^3.s^{-1}$ (112 and 865 ML day^{-1}) provide optimal conditions for this assemblage at this site. The maximum amount of habitat available for this assemblage is 5.75 m^2 per metre of river length and this occurs when flow is at 3.30 $m^3.s^{-1}$ (1,780 $ML.day^{-1}$). Available habitat for this assemblage is very limited when flows are <0.20 $m^3.s^{-1}$ (17 $ML.day^{-1}$). At this flow, the surface area covered by water in the channel falls to only about 9 m^2 per metre of river length, and of this <1 m^2 is available as habitat to maintain aquatic macroinvertebrate abundance.

The faunal rating curves were used to convert the time series of 'natural' streamflow (from the hydrological model for the catchment) into a time series of habitat availability for each assemblage. However, because this component of the assessment focuses on the low flow aspect of the water regime, a procedure known as 'baseflow separation' was performed (using the Lyn-Hollick filter for digital baseflow separation, with an alpha-value of 0.97). 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. The resulting baseflow time series (a section of which is shown in Figure D4) maintains variability in the underlying baseflows and removes the more variable higher flows caused by runoff which are less relevant to the derivation of minimum environmental flows.

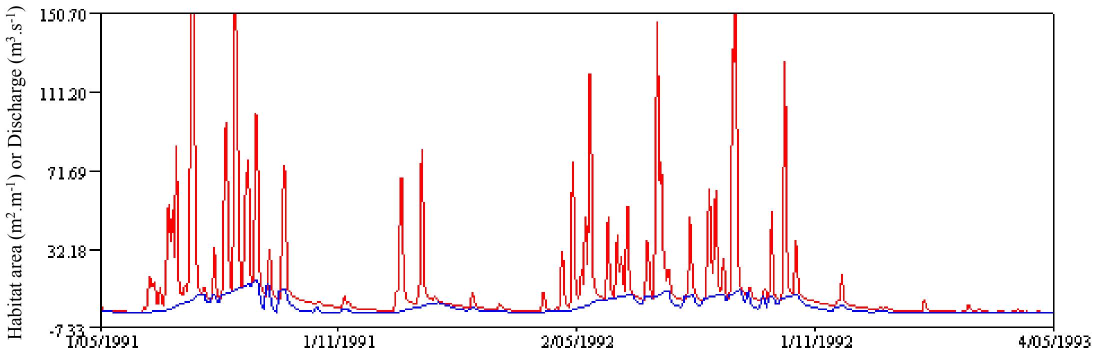

Figure D4: Time series of modelled 'natural' flow (red) and baseflow (blue) for the South Esk River at Malahide for the period May 1991 to May 1993. Baseflow separation from the modelled 'natural' flow was performed using the Lyn-Hollick filter for digital baseflow separation, with an alpha-value of 0.97.

The baseflow time series was then used to generate a time series of changes in available habitat within the river using the rating curves for the mobile fauna assemblage and macroinvertebrate abundance. Examples of the resultant data are shown in Figure D5, which compares changes in habitat availability for 'mobile' and 'benthic' fauna assemblages with changes in daily average streamflow and baseflow. It is clear from the habitat-availability time series for the 'mobile' fauna (the orange line in Figure D5) that higher flows create unfavourable conditions and decrease the availability of preferred habitats for this assemblage (i.e. there is an nearly an inverse relationship between the changes in baseflows and habitat availability).

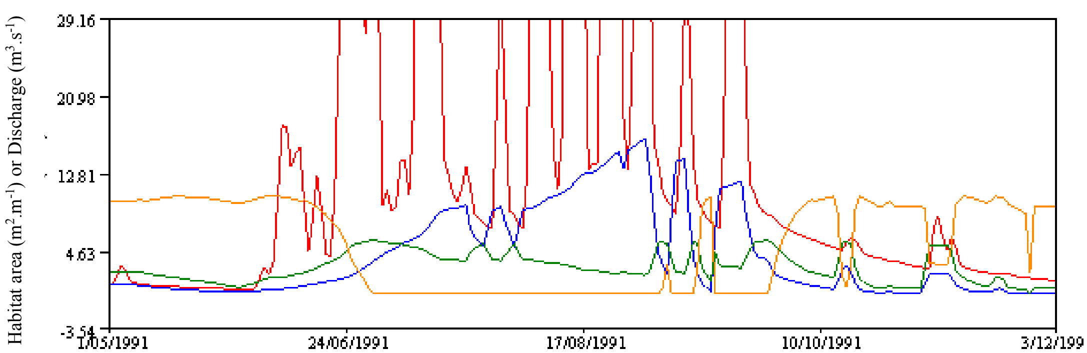

Figure D5: Time series of modelled 'natural' flow (red) and baseflow (blue) for the South Esk River at Malahide, along with modelled changes in habitat availability for the 'mobile' fauna assemblage (orange) and macroinvertebrates (green) for the period May to December 1991.

The time series in Figure D5 implies that the availability of preferred habitat for the 'mobile' fauna falls to zero at times of elevated baseflow. However during these periods the taxa included in this assemblage will actually seek refuge in low-velocity areas such as within snag piles, behind large obstructions and, for crayfish, in the banks or bed of the river. Thus, whilst the amount of preferred habitat is reduced, refuge habitats will always be available as long as the physical structure of the river remains in a natural condition.

In contrast, the habitat-availability time series for macroinvertebrates (the green line in Figure D5) shows that habitat availability increases with an increase in flow.

Therefore, higher flows provide favourable conditions and increase the availability of preferred habitats for this assemblage. As flow declines, the amount of modelled habitat within this section of the river decreases, falling to zero when flows fall below 0.05 $m^3.s^{-1}$ (4 $ML.day^{-1}$). When flow falls to this level, although the fringing macrophyte beds still remain wetted and provide habitat for littoral invertebrates, the amount of suitable habitat for invertebrates inhabiting the bed of the river is greatly reduced.

From the examination of how habitat availability varies with flow for the two faunal assemblages, it is clear that during periods of low flow (i.e. summer) it is the availability of habitat to maintain macroinvertebrate abundance that becomes most restricted. This is further illustrated when the time series of habitat availability for each assemblage is aggregated and plotted as average habitat availability on a monthly basis (Figure D6).

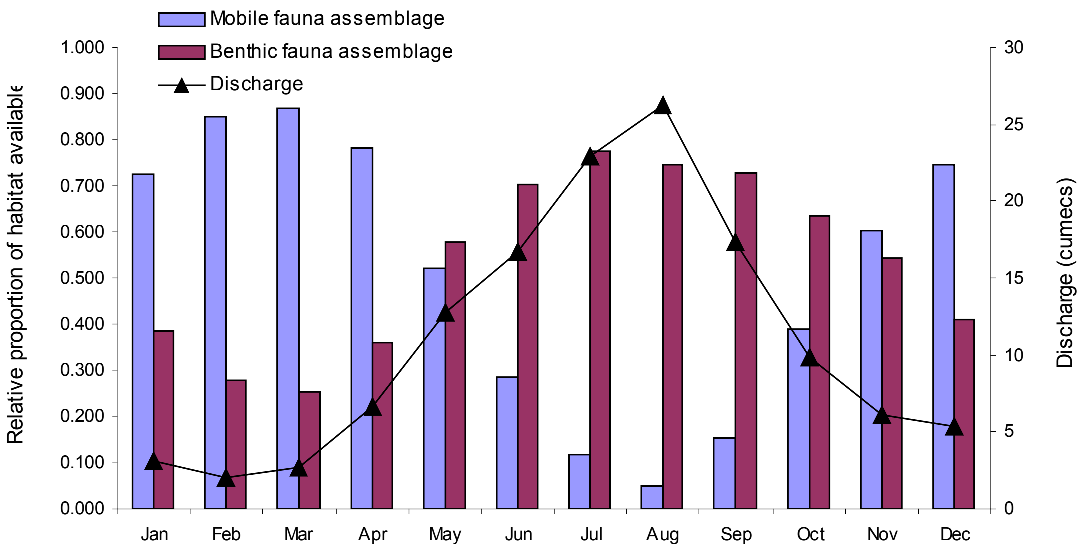

Figure D6: Average proportion of stream area available as habitat to maintain macroinvertebrate abundance and 'mobile fauna' (bars) in the upper South Esk River at Malahide and average monthly 'natural' flows (line). The proportion of habitat available is a function of the area that is actually available under average monthly baseflows relative to the maximum area this is available at the preferred flows of each assemblage.

Clearly, there is significant seasonal variation between the times when habitat availability peaks for each assemblage. The highest proportions of preferred habitat for the 'mobile' fauna assemblage are available between December and April, when average monthly flows are ≤ 5 $m^3.s^{-1}$ (≤ 432 $ML.day^{-1}$). For the remainder of the year, the availability of preferred habitat is more limited for this assemblage. The highest proportions of preferred habitat which maintain macroinvertebrate abundance occur between May and November, when average monthly flows are ≥ 10 $m^3.s^{-1}$ (≥ 865 $ML.day^{-1}$).

This comparison shows that during the dry months of December to April, when monthly average falls below about 5 $m^3.s^{-1}$, and average baseflow falls below about 1.0 $m^3.s^{-1}$ (86.4 $ML.day^{-1}$), habitat for macroinvertebrates is limited. Therefore, it is appropriate that during these months the minimum flow recommendations are aimed at providing adequate habitat for this component of the aquatic fauna community.

To assist in determining a minimum flow level, the time series of habitat area available for macroinvertebrates as 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 calculated. The results of these analyses are graphically presented in Figure D7, which shows the monthly change in selected percentiles of habitat area available for the macroinvertebrate assemblage at the Malahide reach. There is a significant decline in the amount of habitat available for maintaining macroinvertebrate abundance during February and March. During these months, the 85th percentile is less than half of what is available during winter and spring.

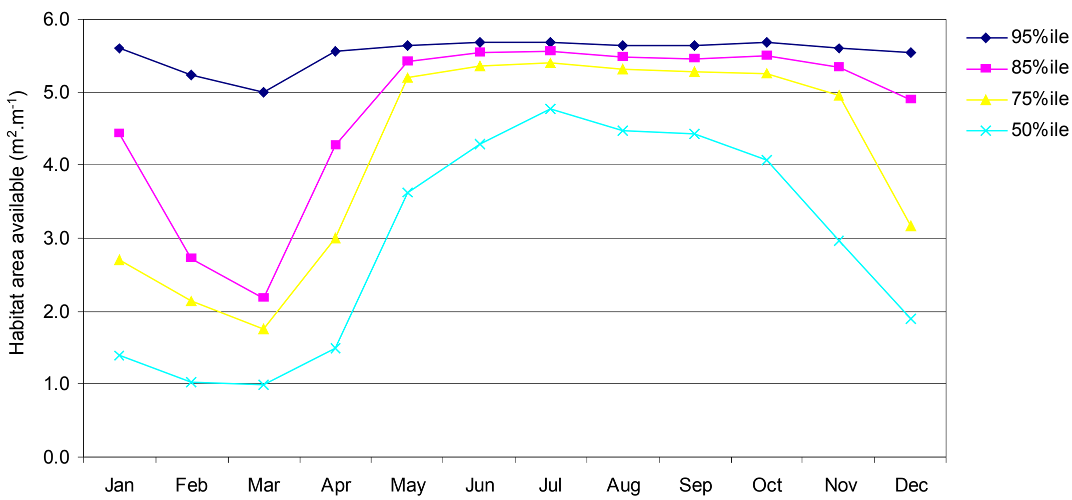

Figure D7: Monthly change in selected percentiles of habitat area available for the macroinvertebrate abundance in the South Esk River at the Malahide site using modelled 'natural' baseflows from 1960 to 2003.

Table D2 provides an indication of the flows (as daily averages) which provide varying amounts of habitat for macroinvertebrate communities within this study reach. 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. However, in developing minimum flow recommendations, some consideration must also be made for flows that maintain longitudinal connectivity and the wetting of lateral benches within the river channel. Inspection of the elevation data in the hydraulic model showed that a flow of approximately 0.15 $m^3.s^{-1}$ maintains approximately 0.05 m of water over the hydraulic jumps that occur within the reach, and provides adequate connectivity between pools. Lateral benches that occur in the middle and lower sections of the reach are inundated at 0.70-0.95 $m^3.s^{-1}$, which is within the range of flows that maintain 75% of habitat for macroinvertebrate abundance.

Table D2: Monthly 85th, 75th and 50th percentiles of instream habitat for macroinvertebrate abundance at Malahide derived from 'natural' baseflow data, and the corresponding flows that provide 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	5.30	2.32	3.63	1.45	1.40	0.37
Feb	2.71	1.08	2.14	0.75	1.02	0.27
Mar	2.17	0.74	1.76	0.53	0.98	0.24
Apr	4.28	1.70	3.00	1.21	1.48	0.40
May	5.42	3.22	5.20	2.11	3.62	1.45
Jun	5.54	2.85	5.36	2.45	4.29	1.70
Jul	5.55	2.87	5.40	2.55	4.78	1.88
Aug	5.48	2.72	5.31	2.34	4.46	1.76
Sep	5.46	2.68	5.27	2.26	4.43	1.75
Oct	5.49	2.73	5.25	2.22	4.06	1.61
Nov	5.34	2.41	4.96	1.95	2.96	1.19
Dec	4.90	1.93	3.16	1.27	1.89	0.60

4.1 Recommendations for minimum flow provisions

Although the data in Table D2 provide useful information regarding the amount of habitat that 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 D2 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 they represent minimum flows that would occur in the absence of agricultural water extraction.

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 option. At the other end of the spectrum, adopting a minimum flow that will maintain only 50% of instream habitat is less likely to sustain a healthy and productive aquatic ecosystem. Whilst the rating curve for the mobile fauna shows that these flows (0.25-1.6 $m^3.s^{-1}$) will maintain a reasonable amount of habitat for the mobile fauna assemblage, in particular juvenile and adult blackfish, there is greater risk that flows during the summer period may provide insufficient habitat to maintain invertebrate abundance.

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 much less conservative than adopting an 85th percentile, if it is considered as an 'absolute limit' (i.e. as a cease-to-take flow), it will limit the temporal extent of flow-related 'stress' to the ecosystem. Adopting the 50% habitat maintenance flow as a 'cease-to-take' limit means that the ecosystem will continue to be exposed to periodic 'acute stress' during periods of extreme low flows, but it will limit the risk of 'chronic stress' associated with prolonged and frequent exposure to these conditions.

On this basis, it is recommended that an environmental flow for the upper South Esk River should maintain 75% of instream habitat for aquatic macroinvertebrates, and that this is 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 a suitable 'cease-to-take' flow. The monthly flows that correspond to these levels are provided in Table D3.

Table D3: Recommended environmental flows and 'cease-to-take' flows for the South Esk River at Malahide.

Month	Environmental flow (75% habitat maintenance flow) ($m^3.s^{-1}$)	Cease-to-take flow (50% habitat maintenance flow) ($m^3.s^{-1}$)
Jan	1.45	0.37
Feb	0.75	0.27
Mar	0.53	0.24
Apr	1.21	0.40
May	2.11	1.45
Jun	2.45	1.70
Jul	2.55	1.88
Aug	2.34	1.76
Sep	2.26	1.75
Oct	2.22	1.61
Nov	1.95	1.19
Dec	1.27	0.60

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 'freshes' created by brief rainfall events, '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 maintaining the form and character of the river (Gippel, 2001), as well as creating a diversity of hydraulic environments that support instream flora and fauna (Biggs *et. al*., 2005; Thoms, 2006). It is important, therefore, when making judgements about components of the flow regime that are required to sustain river ecosystems, some consideration is made of the characteristics (e.g. timing, frequency, magnitude, rate of rise and fall, etc.) 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.

High spells analysis was conducted for the South Esk River at the Malahide study reach using the 20% exceedance* (12 $m^3.s^{-1}$or 1,036 $ML.day^{-1}$), 10% exceedance (26 $m^3.s^{-1}$or 2,246 $ML.day^{-1}$) and 5% exceedance (45 $m^3.s^{-1}$or 3,890 $ML.day^{-1}$) flows as thresholds (Tables D4, D5 and D6). Because this reach is situated relatively high in the catchment and, hence, events rise and fall quite quickly, high spell 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 20% exceedance flow threshold was used to examine the seasonal frequency and duration of smaller events that could be classified as 'freshes' or '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).

Visual examination of all of the transects within the hydraulic model for this reach showed that at the 20% exceedance flow, water is flowing through all of the minor instream channels, and most fringing 'lateral benches' are inundated. The estimated average water velocity throughout the reach at this discharge is 0.70 $m.s^{-1}$.

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

At the 10% exceedance flow, all of the divided channels that occur in this reach are flooded to depths of ≥0.40 m and the average water velocity throughout the reach is approximately 0.85 $m.s^{-1}$. The 5% exceedance flow level (45 $m^3.s^{-1}$) approximates bank-full floods, when critical bank erosion and sediment transport processes operate to maintain channel shape and form. At this flow magnitude, the estimated average water velocity throughout the reach exceeds 1.0 $m.s^{-1}$.

Table D4: Summary of 'high spells' analysis of the 20% exceedance threshold (12 $m^3.s^{-1}$ or 1,036 $ML.day^{-1}$) using 'natural' flow data for the South Esk River at Malahide. This threshold approximates minor 'freshes' or 'flushing' events in this reach.

	Average frequency	Average duration (days)	Average magnitude ($m^3.s^{-1}$)
Spring	2.9	6.6	59
Summer	0.7	4.9	56
Autumn	1.7	7.0	104
Winter	4.2	10.1	91
Annual	8.9	8.2	76

Table D5: Summary of 'high spells' analysis of the 10% exceedance threshold (26 $m^3.s^{-1}$ or 2,246 $ML.day^{-1}$) using 'natural' flow data for the South Esk River at Malahide. This threshold approximates flows that inundate all of the minor channels in this reach.

	Average frequency	Average duration (days)	Average magnitude ($m^3.s^{-1}$)
Spring	1.9	4.3	81
Summer	0.4	3.9	75
Autumn	1.1	4.5	116
Winter	3.2	6.6	106
Annual	6.4	5.7	100

Table D6: Summary of 'high spells' analysis of the 5% exceedance threshold (45 $m^3.s^{-1}$ or 3,890 $ML.day^{-1}$) using 'natural' flow data for the South Esk River at Malahide. This threshold approximates flows that result in bank-full floods in this reach.

	Average frequency	Average duration (days)	Average magnitude ($m^3.s^{-1}$)
Spring	1.2	2.9	105
Summer	0.2	3.6	110
Autumn	0.7	3.9	179
Winter	2.7	3.9	118
Annual	4.8	3.7	123

Tables D4-D6 show that there is a distinct seasonal pattern in the frequency of high flow events, irrespective of their magnitude, with events being most frequent in winter and spring; this is likely to correspond with the seasonal variability in rainfall. On average, events with a 20% exceedance threshold occur 9 times per year and have a duration of 8 days, whilst events with a 5% exceedance threshold occur 5 times per year and last for 4 days. The average annual magnitude of these larger events is approximately 120 $m^3.s^{-1}$ (10,400 $ML.d^{-1}$), although the average magnitude in autumn (when deep low-pressure systems tend to develop off Tasmania's north-east coast resulting in high rainfall events) is much higher at about 180 $m^3.s^{-1}$ (15,500 $ML.d^{-1}$).

The data in Table D7 show the average duration and rates of rise and fall in the hydrograph for the river at the 'Malahide' study reach. 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 D7: Average duration of rise and fall in flow and rates of change in flow, for the South Esk River at 'Malahide'.

Statistic	South Esk River at 'Malahide'
Mean duration of Rises (days)	2.4
Mean rate of Rise ($m^3.s^{-1}.d^{-1}$)	9.0
Mean duration of Falls (days)	7.5
Mean rate of Fall ($m^3.s^{-1}.d^{-1}$)	6.9

Tables D4-D7 show the average seasonal distribution, size, duration and rates of change of ecosystem-relevant flow pulses, but flows may also vary between years. Figure D8 illustrates inter-annual variations in hydrographs for the years 1986 and 1983, along with the 5% exceedance flow threshold. The time series for 1986 displays what could be considered a normal seasonal flow pattern, where high-flow events commence in late autumn and decline again in late spring. During 1986, events exceeding the 45 $m^3.s^{-1}$ threshold occurred a total of 11 times, four of which were large events exceeding 100 $m^3.s^{-1}$. In contrast, the flow regime of 1983 shows a much less seasonal pattern, with only 4 events reaching the 'channel maintenance' flow threshold of 45 $m^3.s^{-1}$. This comparison highlights the substantial climatic variation that can be experienced between years. This should be taken into account when making recommendations regarding the provision of flood waters for the environment.

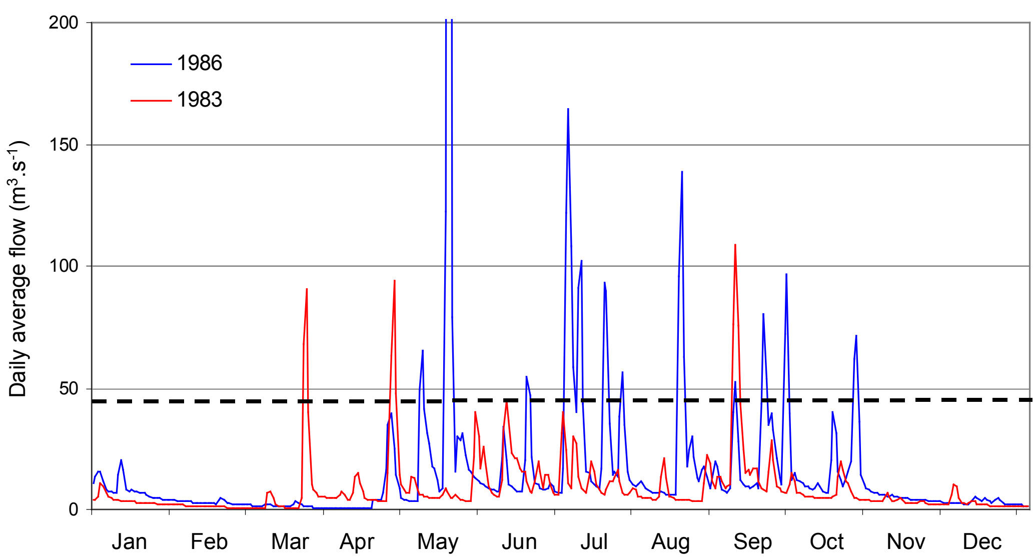

Figure D8: Average daily 'natural' flows in the South Esk River at the Malahide study reach during 1986 (blue) and 1983 (red), along with the 5% exceedance flow threshold (dashed horizontal line). This threshold represents 'channel maintenance' flow events.

Given that the current availability of water for agricultural use during the summer is limited and water managers are encouraging the extraction of water during winter – spring, these high spells analyses provide a good basis from which to make recommendations regarding environmentally sustainable extractions of flood water. One of the environmental objectives under 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 this reach exceeds 26 $m^3.s^{-1}$. Extraction of flood water during this time should not be allowed to significantly affect flood duration and to ensure this it is recommended that 450 $ML.day^{-1}$ be made available for extraction for up to 4 days once 26 $m^3.s^{-1}$ is exceeded, or until flow falls below this threshold. This volume of water, representing about a fifth of the 10% exceedance flow threshold, 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 26 $m^3.s^{-1}$ occur on average about 6 times per year, this makes approximately 10,800 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 45 $m^3.s^{-1}$ 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 river systems (Poff, *et al.*, 1997; Webster, *et al*., 2000). In a dry year, these events may constitute a large proportion of the variability in the flow regime, and it is these events that are most impacted by the proliferation of dams within catchments. In the case of the South Esk catchment, these events are presently provided some measure of protection by the 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 three river systems.

It should also be recognised that the recommendation made here needs to be considered in light of similar recommendations made for locations further 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 upper reaches of the South Esk River relate to the high priority riparian and floodplain plant communities, highly valued aquatic fauna and fish, 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 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 pattern and shape of the high flow components of the flow regime.

Monthly minimum flows have been recommended with the aim of maintaining sufficient habitat to sustain 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 for the upper catchment. Although the primary aim has been to assist with the management of agricultural water extraction during the irrigation period (October to April), recommendations have been provided that cover the rest of the year, and should be used to 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 conjunction with rules for water extraction that presently exist as part of Hydro Tasmania's water management process, and similar recommendations that have been made elsewhere in the catchment.

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