APPENDIX C: Environmental Flows Assessment for the South Esk River at Ormley

1. Description of study reach

This site on the South Esk River is located on the Ormley property approximately 13 km upstream of the township of Avoca and 2.5 km upstream of the confluence of Storys Creek. At this location, the river has an active channel width of about 14-20 m. During low flows, this reach contains defined pools (depths typically >0.9 m) that are connected by glides and shallow riffles (depths typically <0.5 m).

The river at the study reach is composed almost entirely of dolerite rock of pebble and gravel size categories, with some boulder and bedrock present in sections where there is a change in gradient. Based on surveys of thalweg* elevation along the 220 m of the study reach, the overall gradient of the river at this site was estimated to be about 0.00044 (or 0.44 m of fall per kilometre of river distance).

This site is located in an area of the South Esk catchment that is used for agriculture (grazing and cropping) and, hence, it has been substantially modified from its natural condition. Although some parts of the active river channel are steep and indicate active erosion processes, other areas of the river bank are covered by a mixture of small stands of woolly teatree (*Leptospermum lanigerum*), *Eucalyptus* species, willows (*Salix* spp.), European gorse (*Ulex europaeus*), *Poa* grasses and herbaceous species (Plate C1 & C2). The immediate floodplain at this site is dominated by pasture grasses and gorse, but also has remnant areas of *Poa* grasses. The river bed, in both pools and riffles, is generally covered by a thick layer of benthic algae and a fine layer of silt; however, beds of submerged macrophytes and some snags in the form of woody debris are also present.


Plates C1 & C2: Photos of the South Esk River at the Ormley site, showing the mixture of native and exotic vegetation that is found on the river bank and floodplain. A typical shallow riffle and instream submerged macrophytes that occur in shallow areas during periods on low flow are also indicated.

2. Environmental Values and Objectives

Under the CFEV program, the reaches of the South Esk River around the Ormley site have been assessed as having a 'low' degree of naturalness* (CFEV 2005); however, this stretch of river has a 'very high' conservation management priority potential*. According to the CFEV database the main values that drive the conservation management priority for this part of the river relate to the terrestrial vegetation community through which it flows.

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

However, there are also a number of special values that relate specifically to the aquatic ecosystem, namely:

- High priority riparian plant communities
- Lowland *Poa* grassland
- South Esk pine (*Callitris oblonga*)
- Tall quillwort (*Isoetes elatior*)
- Caddis fly (*Oxyethira mienica*)

Additional to these special values, other important biophysical classes are highlighted within the CFEV database. These relate to the fish assemblage that inhabits this area of the catchment, freshwater crayfish that occur within the region, and the characteristic aquatic plant communities that occur in the 'broadwaters' of the South Esk and Macquarie river systems. 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 report.

In summary, an environmental flow for the middle 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 species),
- endemic freshwater crayfish (*Astacopsis franklinii*),
- platypus (*Ornithorynchus anatinus*),
- aquatic and riparian plant communities within the river corridor,
- the endemic freshwater mussel (*Velesunio moretonicus*),
- aquatic macroinvertebrate[*] communities,
- riverine productivity and basic foodweb structure, and
- ongoing geomorphic processes.

Based on this information, Table C1 presents the environmental objectives that an environmental flow allocation should address and the flow components that are required to in achieve these objectives. Further information about the flow components, such as their frequency, timing and magnitude are provided in Chapter 2 of the main report. The main report also provides references to the published literature that illustrate the importance of these flow components to riverine ecosystems.

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

Table C1: Environmental objectives of the environmental flow assessment for the South Esk River at the Ormley study reach, and the important components of the flow regime that support the objectives.

Environmental objectives for the middle reaches of the South Esk River	**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 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 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.

Table C1 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, the impact of current water use on the flow regime at the study reach 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, where the degree of alteration in the hydrological regime of rivers throughout the catchment has been examined based on the likely impacts from current water use (Chapter 4) and a conceptual understanding of the river system. The hydrological analysis of the Avoca to Break O'Day sub-region (summarised in Chapter 3 of the main report) shows that the current flow regime is essentially unmodified, and that the combined water use in the middle and upper catchment (as of 2003) impacts only slightly on the low flow component of the flow regime. Subsequently, the following environmental flow assessment for the South Esk River system between Avoca and Fingal focuses on providing information on what constitutes 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 presently 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

The assessment of minimum flows for the river aims to provide sufficient water to sustain the needs of instream fauna and maintain environmental processes during the drier periods of the year, when water extraction places greatest stress on the river system. To do this, information on channel morphology and habitat preferences of biota are used as input to a hydraulic-habitat computer simulation modelling procedure. 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. For the assessment at the Ormley site, physical and hydraulic data were collected from 12 transects within a 220 m stretch of the river, which was chosen as being representative of the river in this area. While some electrofishing was undertaken to confirm existing data on the fish community inhabiting the river at this location, no additional biological information was collected. Information on the habitat-use preferences of biota was derived from similar studies previously undertaken in the river and the nearby St Pauls River by DPIW and other researchers (see the main report for references).

The minimum flow requirements for the South Esk River at the Ormley site were assessed by using known habitat preference information (i.e. depths and velocities) for fish species that were present, general macroinvertebrate abundance, the South Esk freshwater mussel, native freshwater crayfish (*Astacopsis* spp.) and platypus. 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 in the habitat requirements of certain taxa in the faunal community.

Biota that live predominantly above the bed of the river and are more mobile (i.e. fish, crayfish and platypus) tend to prefer water depths and velocities that occur under lower flows, in particular native fish such as the southern pygmy perch. The habitat-use curves for these biota were able to be combined to form a 'mobile' fauna assemblage curve (Figure C1). This habitat-use curve includes the habitat preferences for adult and juvenile brown trout (*Salmo trutta*). Although brown trout are an introduced species and are known to prefer higher flow velocities, the inclusion of this species did not markedly alter the rating curve that was derived using only the habitat preference information of native species. The reason for this is not very clear, but is thought to be due primarily to the low-flow preferences of the southern pygmy perch (*Nannoperca australis*) and juvenile blackfish (*Gadopsis marmoratus*). By meeting the needs of these two species, the habitat requirements of other fish species will also be met.

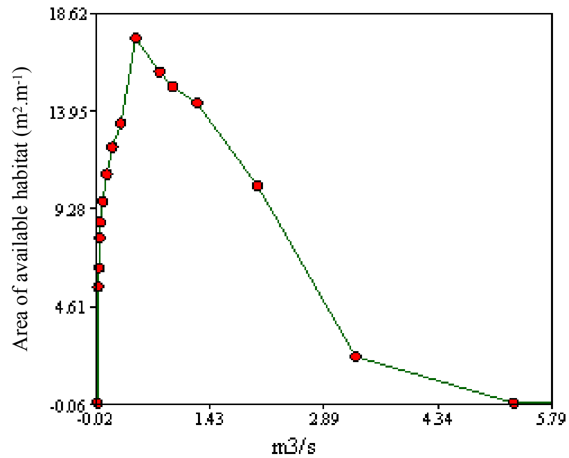

Figure C1: The 'mobile' fauna assemblage habitat-use curve for the South Esk River at the Ormley site. This rating curve, which shows how habitat availability varies with changes in flow, is derived from the amalgamated information on habitat preferences for native and introduced fishes, crayfish and platypus.

In a similar manner the habitat-use information for the large, endemic freshwater mussel and macroinvertebrate abundance was combined to produce a 'benthic' fauna assemblage curve (Figure C2). The size of the curve suggests that habitat for this component of the faunal community is much more prevalent at the Ormley site (as indicated by the higher peak value on the y-axis). Habitat for this assemblage is also available over a much greater range of flows (5 to 35 $m^3.s^{-1}$). This assemblage is much less mobile and, thus, reliant on the habitat provided by substrates within the river channel. Therefore, it is clearly less affected by the greater water depths and higher velocities that occur during higher flows.

Due to this contrast in the habitat requirements of the two assemblages, these two habitat-use curves (Figures C1 & C2) were used separately to develop minimum environmental flow recommendations.

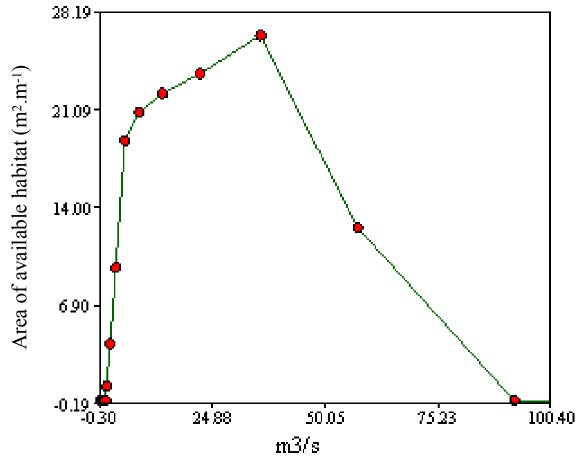

Figure C2: The 'benthic' fauna assemblage habitat-use curve for the South Esk River at the Ormley site. This rating curve, which shows how habitat availability varies with changes in flow, is derived from the amalgamated information on habitat preferences for the freshwater mussel (*V. moretonicus*) and general macroinvertebrate abundance.

The habitat-use curve for mobile fauna (Figure C1) shows that flows between 0.3 and 1.2 $m^3.s^{-1}$ (26 and 104 $ML.day^{-1}$) provide optimal conditions for this assemblage at the Ormley site. The maximum amount of habitat available for this assemblage is 17.4 m^2 per metre of river length and this occurs when flow is at 0.50 $m^3.s^{-1}$ (43 $ML.day^{-1}$). These findings are supported by the known habitat preferences of pygmy perch: they use habitats provided by the macrophyte beds along the fringes of the stream, where there is good cover and low water velocities. Flows between 0.1 and 0.8 $m^3.s^{-1}$ would allow the fringes of the main river channel to have depths and velocities that provide optimal conditions for habitation by these small fish. Higher flows are likely to drown out these beds and threaten to wash these fish downstream.

Conversely, the habitat-use curve for benthic fauna (Figure C2) shows that flows between 5 and 45 $m^3.s^{-1}$ (432 and 3900 $ML.day^{-1}$) provide optimal conditions for this assemblage at the Ormley site. The maximum amount of habitat available for this assemblage is 26.5 m^2 per metre of river length and this occurs when flow is at 35 $m^3.s^{-1}$ (3024 $ML.day^{-1}$). Available habitat for this assemblage becomes very limited when flows are <1.0 $m^3.s^{-1}$ (86 $ML.day^{-1}$).

The faunal rating curves can be used 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 is focused 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 C3 for illustration) reflects the changes in the underlying baseflow and removes the more variable surface flows caused by runoff which are less relevant to the derivation of minimum environmental flows.

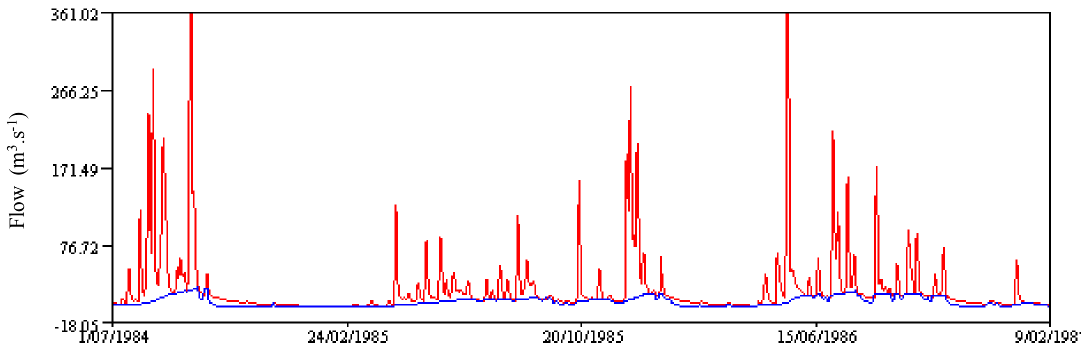

Figure C3: Time series of modelled 'natural' flow (red) and baseflow (blue) for the South Esk River at Ormley for the period July 1984 to February 1987. Baseflow separation from the modelled 'natural' flow was performed using the Lyn-Hollick filter for digital baseflow separation, with an alpha-value 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 shown above. Some results of this are shown in Figure C4, 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 C4) that higher flows create unfavourable conditions and decrease the availability of preferred habitats for this assemblage (i.e. there is nearly an inverse relationship between the changes in baseflows and habitat availability).

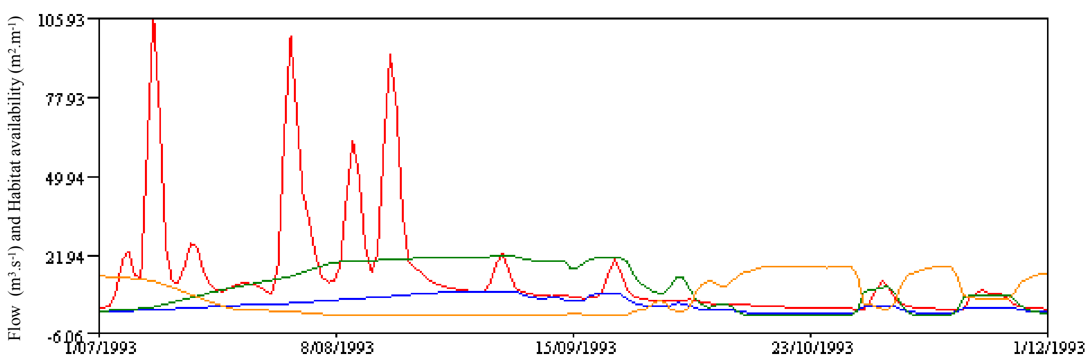

Figure C4: Time series of modelled 'natural' flow (red) and baseflow (blue) for the South Esk River at Ormley, along with modelled changes in habitat availability for 'mobile' fauna (orange) and 'benthic' fauna (green) assemblages for the period July to December 1993. Flow is shown in cumecs ($m^3.s^{-1}$) and habitat availability is shown in square metres per metre of river length ($m^2.m^{-1}$).

Although the time series implies that habitat availability for mobile fauna falls nearly to zero at times of elevated baseflow, during these periods the taxa included in this assemblage will actually seek refuge in low velocity areas such as within snag piles, behind large boulders and (for crayfish) in the banks or bed of the river. Thus, while 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 the benthic fauna (the green line in Figure C4) shows that habitat availability increases with an increase in flow. Thus, high flow events 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 diminishes rapidly, falling to near zero when flows fall below 1 cumec (86 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 (including the freshwater mussel) 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 it is the habitat for benthic fauna 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 C5).

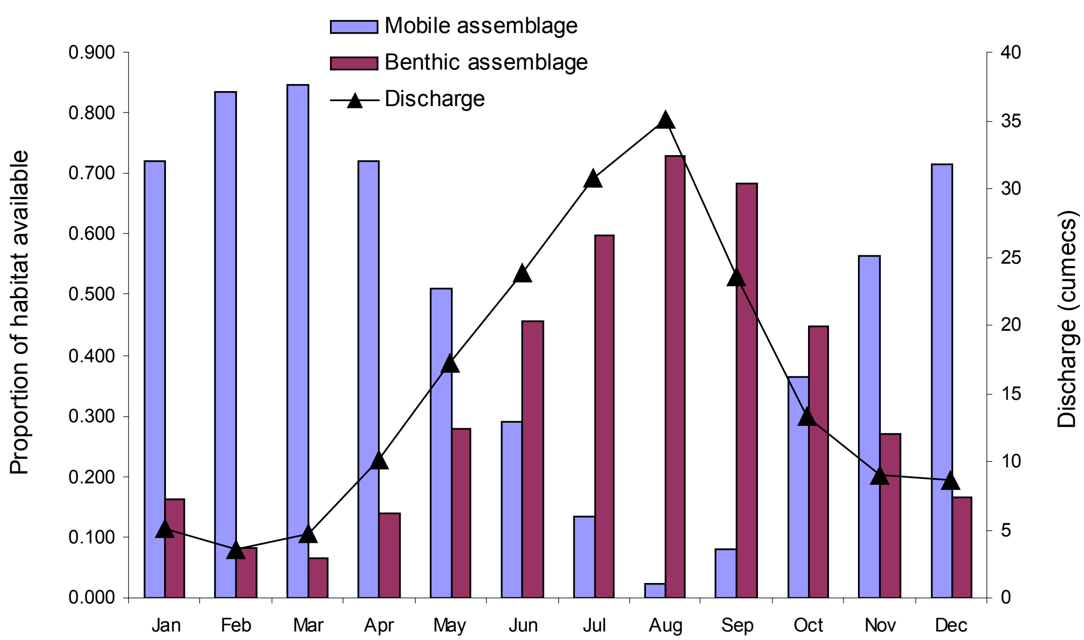

Figure C5: The average proportion of preferred habitat available for the 'mobile' (blue bars) and 'benthic' (red bars) assemblages and monthly average 'natural' flow (black line) in the South Esk River at Ormley. The proportion of habitat available is a function of the area that is available under the monthly average 'natural' baseflow relative to the maximum area that is available at the optimal flows for 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 during January-April when average monthly flows are <10 m^3.s^{-1} (<864 ML.day^{-1}). For the remainder of the year, the availability of preferred habitat is very limited for this assemblage. The highest proportions of preferred habitat for the benthic fauna assemblage are available during June-October, when average monthly flows are >15 m^3.s^{-1} (>1123 ML.day^{-1}).

From this comparison it is clear that during the dry months of December to April, when monthly average falls below 10 m^3.s^{-1} and average baseflow falls below 2 m^3.s^{-1} (172 ML.day^{-1}), habitat for benthic fauna is reduced. Therefore, it is appropriate that during these months the minimum flow recommendations are aimed at providing adequate habitat for the 'benthic' fauna assemblage.

To help in determining a minimum flow level, the time series of habitat area available for benthic fauna 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 computed. The outcome of this analysis is graphically presented in Figure C6. It shows the monthly change in selected percentiles of habitat area available for the 'benthic' fauna assemblage at the Ormley reach. The graph shows that there is a significant decline in habitat availability for benthic fauna during February and March, and that the 75th percentile throughout the summer months is well below 5 $m^2.m^{-1}$.

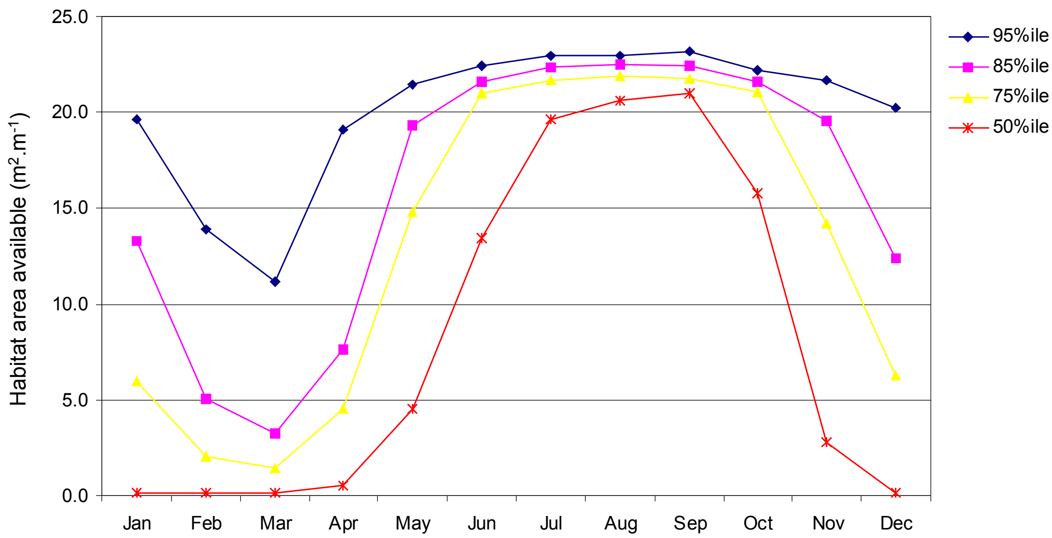

Figure C6: Graph showing the monthly change in selected percentiles of habitat area available for the 'benthic' fauna assemblage in the South Esk River at the Ormley using modelled 'natural' baseflows from 1960 to 2003.

Table C2 provides an indication of the level of flows (as daily average flow) that supports 85%, 75% and 50% of habitat for benthic fauna within the river, recognising that this is the component of the aquatic community that is most likely to be limited by low flow conditions. Knowing the flows that will provide a given 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 connectivity between pools and broadwaters during dry periods, and wetting of lateral benches within the river channel. Inspection of the hydraulic transects for the reach suggests that because of the very low gradient of the river system, a flow of approximately 0.1 $m^3.s^{-1}$ (10 $ML.day^{-1}$) maintains some level of connectivity between pools. At the study reach, this maintains a water depth of ≥0.13 m throughout the reach, including riffles. Inundation of lateral instream benches occurs at 0.8 $m^3.s^{-1}$ (70 $ML.day^{-1}$), which is within the range of flows that maintain 50% of habitat for benthic fauna.

Table C2: Monthly 85th, 75th and 50th percentiles of instream habitat for macroinvertebrate abundance at Ormley 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	13.31	4.10	6.00	2.53	0.14	0.95
Feb	5.06	2.26	2.06	1.50	0.14	0.95
Mar	3.25	1.83	1.44	1.36	0.14	0.95
Apr	7.60	2.82	4.52	2.14	0.55	1.10
May	19.32	5.95	14.79	4.40	4.49	2.13
Jun	21.61	10.94	21.02	9.00	13.42	4.08
Jul	22.37	14.36	21.67	11.44	19.62	6.48
Aug	22.52	15.50	21.90	12.22	20.60	8.07
Sep	22.46	14.58	21.75	11.91	20.97	8.80
Oct	21.63	11.10	21.11	9.34	15.78	4.61
Nov	19.57	6.38	14.22	4.26	2.76	1.68
Dec	12.41	3.81	6.26	2.50	0.14	0.95

4.1 Recommendations for minimum flow provisions

Although the data in Table C2 provide useful information on 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 C2 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 and likely to provide the best protection for instream ecosystem values. At the other end of the spectrum, adopting a minimum flow level 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 (0.9-1.1 $m^3.s^{-1}$) will maintain a reasonable amount of habitat for this assemblage, in particular pygmy perch, there is a greater risk that flows of this magnitude will 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 less conservative than adopting an 85th percentile, if it is considered as an 'absolute limit' (i.e. as a cease-to-take flow) then it should act to restrict the temporal extent of flow-related 'stress' to the 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 will maintain 75% of instream habitat for the benthic fauna in the middle reaches of the South Esk River between Avoca and Fingal is recommended, and 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 C3.

Table C3: Recommended environmental flows and 'cease-to-take' flows for the South Esk River at Ormley.

MONTH	Environmental Flow (75% habitat maintenance flow) ($m^3.s^{-1}$)	Cease-To-Take Flow (50% habitat maintenance flow) ($m^3.s^{-1}$)
Jan	2.53	0.95
Feb	1.50	0.95
Mar	1.36	0.95
Apr	2.14	1.10
May	4.40	2.13
Jun	9.00	4.08
Jul	11.44	6.48
Aug	12.22	8.07
Sep	11.91	8.80
Oct	9.34	4.61
Nov	4.26	1.68
Dec	2.50	0.95

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 'freshets' created by brief rainfall events, 'channel maintenance' events that occur 5-10 times per year, and floodplain inundation events we all perceive 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 support instream flora and fauna (see discussion in Biggs *et. al*., 2005; and Thoms, 2006). It is important, therefore, that when making judgements about components of the flow regime that are 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.

High spells analysis was conducted for the South Esk River at the Ormley study reach using the 20% exceedance* (17 $m^3.s^{-1}$or 1,470 $ML.day^{-1}$), 10% exceedance (35 $m^3.s^{-1}$or 3,025 $ML.day^{-1}$) and 5% exceedance (60 $m^3.s^{-1}$or 5,185 $ML.day^{-1}$) flows as thresholds (Table C4). 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 small 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 corresponds approximately to the level of the 'flood harvesting rule' developed by Hydro Tasmania and 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 water levels at the 20% exceedance flow more than half fill the river channel. The estimated average water velocity throughout the reach at this discharge is about 0.55 $m.s^{-1}$.

The 10% exceedance flow approximates the flow at which water levels appear to inundate most of the river channel in this reach (i.e. a full channel flow). During flows of this magnitude, bank erosion and sediment transport processes will occur, and hence this flow

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

can be viewed as a 'channel maintenance' or 'bank-full' flood flow. The estimated average water velocity throughout the reach at this discharge is approximately $0.75\ m.s^{-1}$.

The 5% exceedance flow level ($60\ m^3.s^{-1}$) approximates over-bank flows, when discharge exceeds the carrying capacity of the channel and is forced out into the riparian areas and the floodplain terraces (where these are present). At this flow magnitude, the hydraulic model suggests that average water velocity throughout the reach exceeds $0.93\ m.s^{-1}$.

Table C4 shows that there is a clear seasonal pattern in the frequency, and to a lesser extent duration, of flow events, with events of all kinds mostly occurring during winter and spring. For all types of events, the duration is significantly longer during winter. Events with a 20% exceedance threshold occur on average about 11 times per year and have an average duration of about 7 days. While there are fewer high spells during autumn, they tend to have greater average magnitudes than the more common events which occur in winter and spring. This reflects the relatively large impact of deep low-pressure systems that tend to develop off Tasmania's northeast coast and result in fairly significant rainfall events.

Within this reach there is little difference between the frequency and duration of 10% exceedance events (equivalent to bank-full) and 5% exceedance events (over-bank flows), despite the latter having a threshold that is 70% higher. This, along with a comparison of the average magnitude data suggests that rainfall events that produce 10% exceedance flows are also likely to exceed the 5% exceedance threshold.

The data in Table C5 show the average duration and rates of rise and fall in the hydrograph for the river at the 'Ormley' study reach. It provides additional information on rates of change in flow that occur, and illustrates that there is a relatively rapid response by the river to runoff, with a short duration (and larger rate) of rise in flow in comparison to fall, a feature that is typical of most rain-fed rivers. 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 C4: High spells analysis of the 'natural' flow data for the South Esk River at the Ormley study reach. The 20% exceedance threshold (17 $m^3.s^{-1}$) approximates minor 'freshes' or 'flushing' events at this reach, the 10% exceedance threshold (35 $m^3.s^{-1}$) approximates bank-full flows, and the 5% exceedance threshold (60 $m^3.s^{-1}$) corresponds approximately with over-bank floods.

	20% exceedence (17 $m^3.s^{-1}$ or 1,470 $ML.day^{-1}$)			10% exceedence (35 $m^3.s^{-1}$ or 3,025 $ML.day^{-1}$)			5% (60 $m^3.s^{-1}$ or 5,185 $ML.day^{-1}$)		
	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	10.6	7.1	91	7.8	4.6	124	5.1	3.6	166
Spring	3.1	6.0	69	2.0	3.6	97	1.2	3.2	134
Summer	0.9	5.4	82	0.5	3.6	117	0.3	3.2	167
Autumn	1.8	5.6	109	1.1	4.3	156	0.7	3.6	227
Winter	5.2	7.9	101	4.0	4.8	119	2.7	3.5	154

Table C5: Average duration of rise and fall in flow and rates of change in flow, for the South Esk River at 'Ormley'.

Statistic	South Esk River at 'Ormley'
Mean duration of Rises	2.9
Mean rate of Rise	10.8
Mean duration of Falls	8.3
Mean rate of Fall	6.7

Tables C4 and C5 show the average seasonal distribution, size, duration and rates of change of ecosystem-relevant flow pulses, but flows may also vary between years. Figure C7 illustrates the inter-annual variations that can occur by plotting the hydrograph for the years 1999 and 2000, along with the level of the 10% exceedance flow threshold. The figure highlights the substantial variations between years in the frequency and magnitude of events. In 1999 (which was generally the drier year), only 3 events exceeded the threshold and these occurred in autumn and winter. In contrast to this, in 2000 the threshold was exceeded 7 time during winter and spring, with another large event occurring in mid-January as a result of an east-coast low pressure system.

Graphs such as these highlight the hydrologic variability that exists in the middle and upper reaches of the South Esk River, and that to preserve this variability care must be taken when developing rules to manage extraction of water from this part of the flow regime.

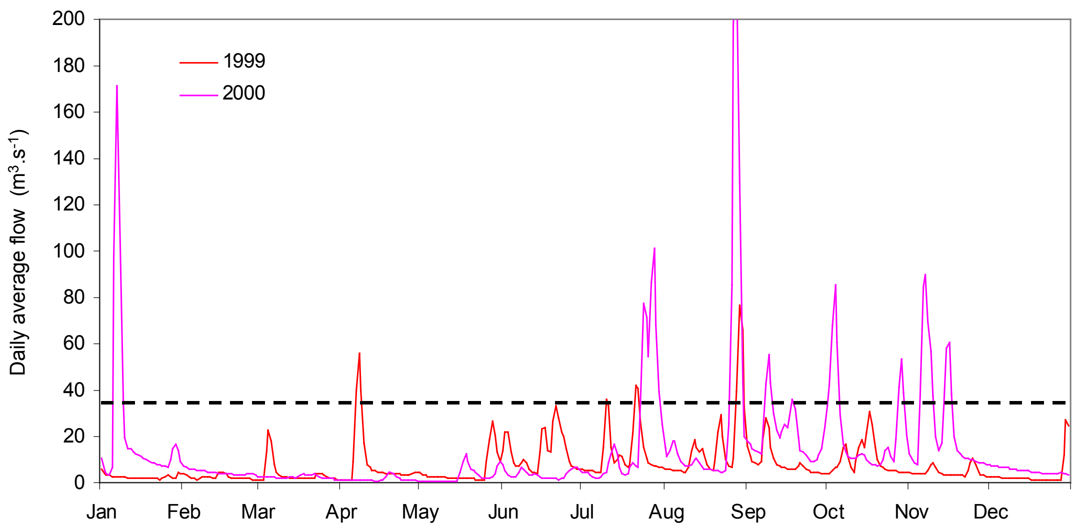

Figure C7: Graph comparing daily average 'natural' flow at Ormley on the South Esk River during 19997 and 2000, along with the 10% exceedance flow threshold used in high spells analysis as representing 'channel maintenance' flows at this site.

In making recommendations for the 'ecologically sustainable' extraction of water from medium to large flow events, it is fundamental that as far as practicable, the natural flow regime of the river is maintained. This is the main premise of the Tasmanian Environmental Flows Framework (TEFF). 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 the wood and organic material upon which instream fauna rely, and rejuvenates riparian vegetation communities. As the data from 1999 clearly illustrates, in the absence of significant rainfall events, it is the smaller flow 'pulses' that provide the main structure to the flow regime, and therefore it is these that must be preserved. Bearing the various roles of floods in mind, the following basic recommendation is made.

5.2 Recommendations for allocation of flood water

It is recommended that the allocation of floodwater only be allowed when flow at this reach exceeds 35 $m^3.s^{-1}$. Extraction of flood water during this time should not significantly affect flood duration and rates of water level change, and to ensure this it is further recommended that 600 $ML.day^{-1}$ be made available for extraction for up to 4 days once 35 $m^3.s^{-1}$ is exceeded, or until flow falls below this threshold. This volume of water, representing about one 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 35 $m^3.s^{-1}$ occur on average about 7 times per year, this makes approximately 16,8000 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 a role in 'relieving stress' on the system (Poff, *et al.*, 1997), mainly by ameliorating water quality (Webster, *et al.*, 2000). In a dry year these events may constitute a large proportion of the variability in the water regime, and it is these events 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 the flood harvesting rules 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 this recommendation regarding the extraction of flood water for the catchment above Ormley needs to be considered in the light of similar recommendations made for locations upstream and downstream of this location. 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 middle reaches of the South Esk River (Avoca to Fingal) relate to the riparian plant communities within the river corridor and floodplain, 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 as much as possible the natural variability in the flow regime. To do this, recommendations have been made regarding monthly minimum flow provisions and extraction rules aimed at preserving the magnitude, duration and rate of change of high flow events.

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. Although the primary aim has been to assist with the management of agricultural water extraction 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, and similar recommendation 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 values that have been identified for the South Esk River and sustain the ecosystem into the future.