DEPARTMENT *of*
PRIMARY INDUSTRIES,
WATER *and* ENVIRONMENT

Tasmania

Index of River Condition for the Duck River Catchment

A report forming part of the requirements for State of Rivers reporting

Rebecca Pinto
Water Assessment and Planning Branch
Water Resources Division
DPIWE.

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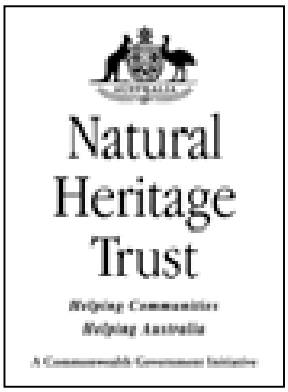

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The Department of Primary Industries, Water and Environment

The Department of Primary Industries, Water and Environment provides leadership in the sustainable management and development of Tasmania's resources. The Mission of the Department is to advance Tasmania's prosperity through the sustainable development of our natural resources and the conservation of our natural and cultural heritage for the future.

The Water Resources Division provides a focus for water management and water development in Tasmania through a diverse range of functions including the design of policy and regulatory frameworks to ensure sustainable use of the surface water and groundwater resources; monitoring, assessment and reporting on the condition of the State's freshwater resources; facilitation of infrastructure development projects to ensure the efficient and sustainable supply of water; and implementation of the *Water Management Act 1999*, related legislation and the State Water Development Plan.

Executive Summary

This report provides a 'snapshot' picture of river condition, in relation to riparian condition, physical in-stream habitat and in-stream structures within the Duck River catchment. The approach adopted for this study is a derivation of the original Index of River Condition (IRC) method utilised in previous 'State of River' reports by the Department (eg: Bobbi *et al.*, 1999).

The IRC methodology originally provided an overall condition rating based on five subindices (Nelson, 1999). Various sub-indices were used to detect changes in condition from a natural state for the parameters of aquatic ecology, hydrology, water quality, stream-side zone and physical form. These sub-indices were taken from the Victorian Index of River Condition and adapted to Tasmanian conditions (CEAH, 1997). As the parameters of hydrology, water quality and aquatic ecology are extensively reported in other sections of 'State of Rivers' reports, IRC reports will now focus on the parameters of physical form and stream-side zone. In addition, a new element "hydrological connectivity" has been added to the assessment in relation to in-stream structures. Hydrological connectivity was assessed in relation to their location and does not necessarily correspond to sites where riparian and physical in-stream habitat was assessed.

Field data collection of IRC parameters occurred at thirty-four sites within the Duck River catchment. Ten of these were located on the mainstream Duck River and twenty-four on tributary streams. A total of forty-six in-stream structures were assessed separately.

On average the physical form sub-index rated as being in near natural condition for both the mainstream and tributaries. However, as with the stream-side zone sub-index, lower values were recorded for sites within agricultural and/or urban areas. This is largely due to poor scores for Coarse Woody Debris (CWD) and Overall Stream Disturbance (OSD).

On average the stream-side zone sub-index rated as in poor condition for the main stream and the tributaries. Typically ratings for this sub-index were lower in agricultural and urban areas than for non-developed zones. These findings indicate that the extensive growth of riparian weed species (primarily willows (*Salix fragilis*) and blackberries (*Rubus fruticosus)*), non-vegetated or poorly vegetated riparian zones and uncontrolled stock access to riverbanks are issues that need addressing.

The hydrological connectivity of the forty-six structures surveyed were found to range in condition from 'good' to 'extensively modified' in relation to in-stream barriers and fish passage in the Duck catchment. Surveys of in-stream structures focused primarily on the hydrological changes that are associated with each artificial structure and how these changes alter the potential for fish passage. Twelve artificial structures were identified to cause alteration of hydrological (fish passage) conditions of the mainstream and/or major tributaries by a moderate to extensive degree. These were found to cause varying degrees of departure from naturalness as a result of structure design.

On average farm dams resulted in an extensive or major modification of conditions, weirs and culverts a moderate modification and bridges a partial modification of conditions. These findings indicate that fish movement patterns may be restricted by artificial structures within the catchment. While the Duck River weir is located in the lower section of the catchment, it was found to have little effect on the movement of fish past this barrier due to the improvement of the structure with the installation of a rock ramp by Inland Fisheries Service in late 2002. This ladder will enable movement of fish under all flow conditions, thereby ensuring hydrological connectivity of the river system to be maintained.

Although the structures assessed under the hydrological connectivity component of the IRC showed that conditions were near ideal for fish movement, it should be noted that there are approximately 194 dams (189 of which are on-stream) located throughout the Duck catchment. While a large number of these dams are located on tributaries, they pose significant barriers to the movement of fish in the absence of fish ladders and risk hydrologically isolating the bodies of water that they are located on. It was beyond the scope of this project however to assess every individual on-stream dam and therefore the cumulative impact that these structures pose can purely be highlighted for attention through the future management of this water resource.

Ten of the twelve native fish species known to occur within the catchment are migratory and require unobstructed passage between sea and river to complete their life cycle. Due to the low number of fish surveys conducted within the catchment it is beyond the scope of this study to determine whether natural or artificial obstructions have the greatest impact on current fish distributions.

It is evident that riparian (stream-side) zone rehabilitation and management is a significant issue for agricultural and urban areas of the Duck catchment. Within urban areas it was found that the riparian zone was highly altered and that native species were in low proportions. Reaches in agricultural areas of the catchment specifically those on tributaries in the lower sections of the catchment, Edith Creek and sections of tributaries within the middle and upper catchment were found to be in poor condition. This was evident by the wide spread infestation of weed species, poor native plant cover and unrestricted stock access. Areas with poor riparian condition should be the focus of future catchment management activities to avoid further degradation, in addition to continued protection of areas that are of high conservation value or undisturbed.

Glossary of Terms

Anadromous	Fish that hatch in freshwater, then migrate to salt water to grow and mature, and inturn migrate back into fresh water to spawn and reproduce.
Amphidromous	Refers to fishes that regularly migrate between freshwater and the sea (in both directions), but not for the purpose of breeding, as in anadromous and catadromous species.
Catadromous	Fish that migrate from fresh water to salt water to spawn or reproduce.
Coarse Woody Debris (CWD)	Dead or living tree (branch or root system) that has fallen into or is immersed (totally or partially) in a stream. Generally with diameter greater than 10cm and length exceeding 1metre.
Discharge	A volume of water passing a given point in unit time.
Fish passage	The directed movement of a fish past a given point in a stream. Particularly relates to the engineering and biological aspects of restoring free passage at barriers.
Fish passage device	Structure incorporated into a barrier to promote fish movement
Fishways	Structures that allow for fish to pass barriers.
Megalitre (ML)	A measure of water equivalent to 1000 000 litres (or about the size of an Olympic swimming pool).
Pools	Deep, still water usually within the main river channel.
Riffles	Areas of fast moving, broken water.
Riparian vegetation	Vegetation on the banks of streams and rivers.
Run	Unbroken, moving waters.
SIGNAL	**S**tream **I**nvertebrate **G**rade **N**umber – **A**verage **L**evel. Grading based on the tolerance or intolerance of macroinvertebrates to various types of pollution and or disturbance
Snags	In-stream fine woody debris.
Substrate	The structural elements of the riverbed: boulder, cobble etc.
WIMS database	**W**ater **I**nformation **M**anagement **S**ystems database, designed for managing water usage and demand data.

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1. INTRODUCTION

This study has been conducted to provide an assessment of riverine habitat condition within the Duck catchment. The study has been carried out in association with other studies undertaken by the DPIWE to form the basis of 'State of Rivers' reporting for the catchment.

The Index of River Condition was implemented in Tasmania to provide a picture of the 'overall health' of reaches within a catchment. This was previously achieved through the assessment of hydrology, water quality, aquatic ecology, physical form and stream-side zone condition. The Tasmanian IRC method provided for an index of change from a natural state and is based on similar survey approaches carried out in Victoria (CEAH, 1995) and Queensland (Anderson, 1993). IRC assessments have been completed for several catchments within Tasmania (Great Forester, Ringarooma, Brid, Pipers and Mersey catchments) and the method has proven to be useful to assess river condition for Tasmanian rivers. In addition, IRC assessments in these catchments have been used by community groups to target rehabilitation activities.

The IRC has changed since its inception to gather information on physical form, stream-side zone and hydrological connectivity (influence of barriers) as State of River reporting already provides comprehensive assessments of hydrology, water quality and aquatic life. Previous aquatic life ratings were based on SIGNAL assessments (Chessman, 1996) and were incorporated into the IRC. The aquatic health of sites in terms of macroinvertebrate community composition is now reported in the Aquatic Ecology section of the "State of Rivers" report using AusRivAS outputs based on Tasmanian river health models (Krasnicki *et al*., 2001).

The broad objectives of the Tasmanian Index of River Condition are detailed below:

- To identify reaches that have been modified in relation to in-stream physical habitat condition.
- To identify reaches where the riparian zone has undergone modification.
- To develop a method for identifying hydrological discontinuities that act as barriers to native fish migration.
- To make recommendations regarding target management areas for in-stream habitat restoration and riparian rehabilitation.

The current IRC methodology is designed to identify reaches within a catchment where habitat modification has occurred. Habitat modification in this case relates to changes to in-stream and riparian vegetation parameters. The approach has been focused to provide more detail on physical river condition via detailed assessment of the riparian zone and in-stream habitat conditions and should not be viewed simply as a truncated version of previous IRC methodologies. It is a tool that is ideal for identifying areas of habitat modification and determining the source of the disturbance. From this assessment specific management issues can be identified not only for individual reaches but the catchment as a whole. The method also provides the basis for long term monitoring of changes in habitat condition as it is intended that Index of River condition assessments would be conducted every five years. This is the review period currently identified for State of River reporting on Tasmanian catchments.

A detailed assessment of in-stream structures that have the potential to acts as barriers has been incorporated into the study. All structures selected for assessment have been rated on their potential to impede fish passage and their affects on the hydrological connectivity of the system. Changes in hydrological connectivity can be a result of natural (waterfall,

rapids) or artificial features (dams, culverts and weirs). This assessment is independent of IRC ratings for physical form and streamside zone scores and therefore is discussed separately. Fish passage is the term used to describe the ability of fish to pass a point in a stream by directed movement. Eleven of Tasmania's twenty-five native fish species are migratory and require free passage in order to maintain population diversity. Barriers can therefore have major implications for fish populations with the potential to cause localised extinctions, reduce fish abundance and lower genetic diversity (Thorncraft and Harris, 2000). Fish passage has been adopted as the measure of ecological integrity for this parameter.

Individual ratings for barriers can be applied to particular stream reaches and the cumulative effect of barriers on sites determined. These findings can be used as a basis for future management of development within the catchment, through the determination of the cumulative effect and location of barriers. In the Duck catchment fish surveys have been conducted sporadically over a period of twenty-three years. A more recent survey conducted in 2002 in conjunction with previous records has given a sound overall spatial coverage of fish distribution for the catchment. As comprehensive fish records are limited for many small reaches in which artificial barriers occur, caution must be taken in attributing the current pattern of fish distribution to the changes in hydrological connectivity associated with these barriers. As such each individual artificial structure has been assessed on the basis of its effect on hydrological connectivity and it is from this assessment that the likely potential for fish passage has been determined.

Assessment of river condition in this study provides a baseline of information that can be used for comparative purposes to observe changes within the Duck catchment over time. Ideally this program should be re-run in five years using the same sites to determine if the overall condition of the catchment has improved or declined. This would be particularly useful for community groups in relation to monitoring the success of current and future restoration projects.

2. STUDY AREA

A general description of the Duck catchment including an overview of vegetation types present, geology of the area, hydrology and land use is given in the introduction section of the State of River report for the Duck River. However it should be noted that the Index of River Condition study was concentrated on the Duck River mainstream and associated tributaries. Other water bodies outside of this catchment that flow into Duck Bay were not considered in this study.

Site assessments were conducted during late February and early March 1999. A total of thirty-four sites were surveyed within the catchment (Figure 1). A table listing all Duck River sites including grid references, altitude and catchment area above the site for each study location is provided in Appendix 1. Ten sites were located on the mainstream and twenty-four sites on major tributaries within the catchment. Each site was selected as being representative of the reach (length of river) where it occurs. Site selection was based on examination of maps and extensive ground truthing prior to the survey. The selection of study sites overlapped with the sites used in the assessment of water quality and river health. This allowed for the incorporation of any existing long-term water information for the catchment into this 'snapshot' assessment. During October 2002 an additional survey of parameters related to hydrological connectivity was undertaken. The survey allowed for the assessment of the potential for in-stream structures to act as barriers to fish migration or movement.

The distribution of fish species throughout the catchment is important for assessing hydrological connectivity and the effectiveness of on-stream structures for fish movement. Records of fish locations have been reviewed for the Duck catchment based on fish surveys

that have been carried out sporadically over the last twenty-three years. The latest survey was conducted in 2002 and concentrated on the main stream of the Duck River as well as all major and some minor tributaries. Table 1 provides a summary of the native and introduced species that are known to occur within the catchment, each individual species movement habit and the number of verified records.

All of the species listed with the exception of *Salmo trutta* are native to Tasmania and of these *Gadopsis marmoratus* and *Nannoperca australis* are the only native fish recorded for the catchment that are non-migratory.

Table 1. Inventory of fish species for the Duck catchment (Inland Fisheries Service database, DPIWE database).

Species name	**Common name**	**Movement**	**Number of records**
Anguilla australis	Short-finned eel	Catadromous	69
Mordacia mordax	Short-headed lamprey	Anadromous	1
Galaxias brevipinnis	Climbing galaxias	Diadromous	2
Neochanna cleaveri	Tasmanian mudfish	Diadromous	2
Galaxias maculatus	Jollytail	Diadromous	104
Galaxias truttaceus	Spotted galaxias	Diadromous	2
Gadopsis marmoratus	River Blackfish	Non migratory	8
Lovettia sealii	Tasmanian whitebait	Anadromous	9
Retropinna tasmanica	Tasmanian smelt	Anadromous	2
Prototroctes maraena	Australian grayling	Amphidromous	2
Pseudaphritis urvillii	Sandy	Amphidromous	41
Nannoperca australis	Pygmy perch	Non migratory	68
Salmo trutta	Brown trout	Anadromous	71

Dam locations within the Duck catchment were identified from the WIMS (Water Information Management System) database and details of all dam sites and capacity are provided in Appendix 2. There are currently approximately 194 dams located within the Duck River catchment, of which 189 are situated on-stream. A map of all on- and off-stream dams is provided in Section 5 within the Hydrological Connectivity discussion (see Figure 9). The location of fish species found in the catchment has been overlayed on this map to give a visual presentation of the effect that on-stream structures have on the movement of fish.

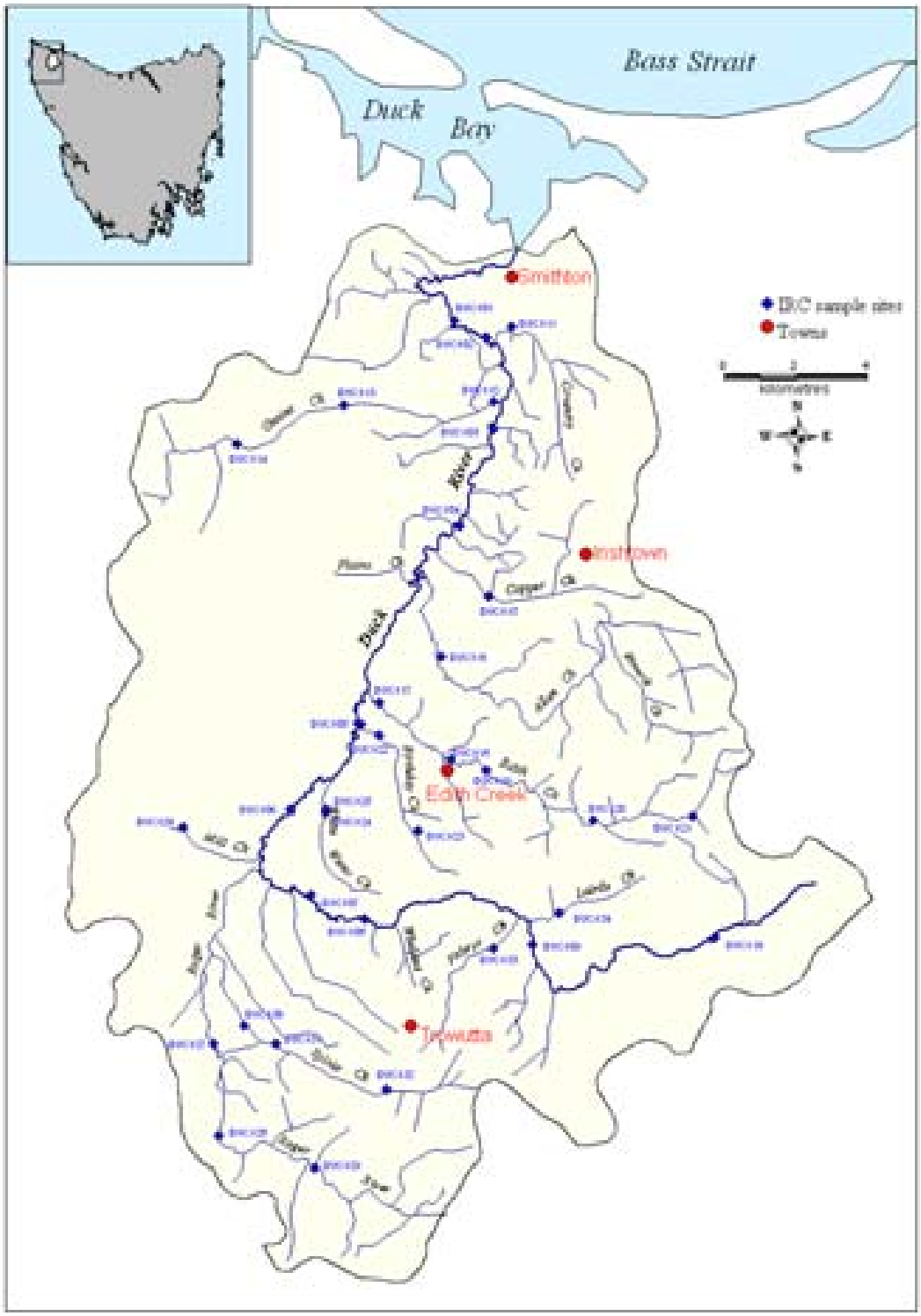

Figure 1. Map of the Duck River Catchment showing location of IRC study sites.

3. METHODOLOGY

The IRC approach has been developed to provide an assessment of current habitat condition within a catchment. This was achieved through the collection of physical and ecological data from a range of reaches throughout a catchment and determining the degree of departure of physical and riparian conditions of these reaches from a natural state.

The methodology is based on three sub-indices (Physical form, Stream-side zone and Hydrological connectivity). Each sub-index represents a rating of one or more parameters or habitat attributes (Table 2).

Table 2. The sub-index parameters with associated indicator categories.

Sub-index	**Indicator**
Physical form	Bank condition Bed condition Density of coarse woody debris Influence of artificial barriers Overall site disturbance
Stream-side zone	Width of stream-side zone Structural intactness Native vegetation cover Native Vegetation regeneration Longitudinal continuity Overstorey regeneration Stream-side cover
Hydrological connectivity	Barrier effectiveness Barrier location Fish passage potential Deviation of flow Other in-stream structures Bank stability Overall disturbance

Parameters for each sub index are rated on a five point rating scale where possible rather than absolute values (Table 3). The ratings are based on the degree of divergence of the current state from a natural state. The 5 point rating scale had been developed for the Victorian IRC (CEAH, 1997a) after rigorous trial of the original Index for Victorian conditions and this has subsequently proven to be an appropriate rating scale for Tasmanian catchments. According to Victorian authorities a scale with a higher or lower rating would be unrealistic given the current state of knowledge of the relationship between a change in the indicator and environmental effects (CEAH, 1997a).

Table 3. Habitat rating categories for individual sites.

Condition	**Very poor** **Highly modified**	**Poor** **Major modification**	**Moderate** **Some modification**	**Good** **Near natural**	**Excellent** **Essentially natural**
Total score	0 - 1	2 - 3	4 – 5	6 - 7	8 - 10
Habitat rating	0	1	2	3	4

3.1 Sub-index parameters

At each site a number of indicators for each sub index are assessed or rated. Descriptions of the indicators for each sub-index parameter are detailed as follows.

3.1.1 Physical form

Bank condition

Bank condition or stability is an assessment of the amount of erosion occurring at set points within the study site. Potential indicators of current bank stability include:

- Lack of vegetative cover or exposed soil.
- Irregularities and sharp bends in the stream course.
- Undermining of the toe of the banks and exposed roots.
- Water discolouration along the toe of the bank, and evidence of recent soil slips.

Bed condition

Bed condition is a measure of overall aggradation and degradation of the stream bed at each transect location. Potential indicators of current bed instabilities include:

- Erosion heads.
- Bank instabilities on both sides of the bank (this indicates bed degradation).
- Any accumulations of sediment around obstructions (typically coarse woody debris) and the general width to depth ratio is low for degradation and high for aggradation.

Density and origin of coarse woody debris (CWD)

In-stream woody debris can represent an important habitat for aquatic animals. It provides a refuge for fish and invertebrates, food source for many macroinvertebrates, and is important for spawning for some fish species (e.g. river blackfish, *Gadopsis marmoratus*). The rating scale is based on the proportion of available CWD in the reach assessed. The rating assumes that the greater the proportion of snags available, the more habitat there is for in-stream fauna.

Influence of artificial barriers

The presence of artificial barriers indicates a clear change from natural conditions. Barriers include weirs, dams, culverts and bridges. Barriers largely affect fish movement but also impact available water downstream which can have an effect on other ecosystem processes. The rating for artificial barriers is based on seasonal changes in water availability across the structure and the frequency of structure inundation.

Overall site disturbance

For this parameter six disturbance categories were available (extreme, very high, high, moderate, low and very low) for each site. The categories are largely based on physical aspects of stream-side vegetation such as the degree of weed infestation, cover provided by native species and native species richness. Details of the six disturbance categories utilised in determining this parameter are provided in Appendix 5.

3.1.2 Stream-side zone

Riparian vegetation plays an important role in the maintenance of stream condition. For example, Skills and Pen (1995) note that stream-side vegetation can provide the following:

- Increase bank roughness thereby reducing erosion potential.
- Riparian roots bind and reinforce soil (bank stabilisation).
- Roots loosen soil allowing greater infiltration of rainwater.
- Vegetation filters sediment and nutrients and promotes sediment deposition.
- Continuous vegetation provides ecological corridors and habitat availability for terrestrial animals and plants.

These factors directly and indirectly maintain the quality and ecological integrity of a waterway.

Width of stream-side zone

The stream-side zone is the interface between the aquatic and terrestrial environment and was assessed as the average distance of vegetation from waters edge at base flow to any cleared or developed land. This parameter is largely designed to determine how much vegetation is present from the riverbank to where some form of disturbance, such as clearing occurs. The stream-side zone may be extensive therefore anything over forty metres should be recorded as such. The width of the stream-side zone is important to determine the buffering effect that it is having from adjacent developed land and to indicate the continuous presence of vegetation which is important for faunal corridors and habitat.

Structural intactness

Structural intactness is an indicator of disturbance relating to the original distribution of stream-side vegetation. The ratings for structural intactness are based on a scale of continuous, patchy and sparse cover. The following definitions for the three structural layers are based on the Victorian model.

- Overstorey – those woody plants greater than 5 m tall.
- Understorey - those woody plants less than 5 m tall.
- Ground cover - other plants without woody stems.

Proportion of native vegetation cover

This category refers to the proportion of native and introduced plant species in the reach assessed. The relative proportion of native species present provides a rating of how close to natural the reach is. The presence of exotic species may be undesirable depending on the quantity and/or the particular exotic species. Ratings are according to the percentage cover that is present and is determined separately for each structural layer.

Presence of regeneration of native plant species

Regeneration of native vegetation is an important indicator of current condition. Due to the difficulty in assessing the regeneration of ground cover species, it has been applied to overstorey and understorey species only.

Longitudinal continuity

In essence longitudinal continuity is simply a measure of how continuous stream-side vegetation is. Any gap that exists in a vegetation corridor has the potential to act as a barrier to terrestrial fauna movement or increase physical and ecological disturbance via erosion/ sedimentation runoff. The parameter specifications adopted here are the result of expert panel discussions in Victoria (CEAH, 1997). A significant discontinuity is defined as a gap in the stream-side vegetation greater than ten metres long and that has a width of five metres or less. The two factors applied are:

- Proportion of bank length with vegetation greater than 5 m wide.
- The number of significant discontinuities per unit length.

Overstorey stream-side vegetation regeneration

The regeneration of indigenous species within the stream-side zone is an important rating of its current condition. A well-developed overstorey suggests long term stability of the area from previous disturbance events such as clearing, logging and fire.

Vegetative regrowth categories

This rating is based on the assumption that natural succession in vegetation culminates in the formation of a climactic community. Such an end point community receives the highest rating. The nature of the climax communities varies and is determined by environmental conditions within an area. For example high rainfall areas of the State support temperate rainforest as a climax community, whilst low rainfall areas may culminate in a sclerophyll community.

Stream-side cover

The indicators for this section are categorised as follows:

- Canopy cover
- Vegetation overhang
- Root overhang
- Bank overhang
- Man-made overhang

The data collected for this section provides an assessment of available habitat in the form of shelter and shading for aquatic life. Overhanging trees may also provide a direct food source in the form of leaf and insect fall into the stream. Man-made overhangs relate to structures (eg: jetties and pontoons) that result in shading and or sheltering of the streambed.

3.1.3 Hydrological connectivity

Hydrological connectivity or the ability of water to move between river reaches has been identified as an important factor in assessing riverine condition. This index has been incorporated to highlight which indicators of hydrological connectivity have undergone modification within the catchment. As with the previously mentioned sub-indices there are a number of parameters that have been identified that allow the formation of a rating scale for hydrological connectivity. A five point rating system has been developed for each parameter and details are given under each parameter heading below. The term "ideal" is used in preference to the term "natural" as used for stream-side zone and physical form. The seven hydrological connectivity parameters (Tables 4 to 10) are described as follows:

*1. **Barrier effectiveness***

This parameter determines the ability of an in-stream structure to act as a barrier.

Table 4. Conditions and rating for barrier effectiveness.

		Rating
Essentially ideal	Structure is present which allows for essentially natural in-stream conditions.	**4**
Near ideal	Potential barrier, open construction with near natural flow.	**3**
Moderate modification from ideal	Small barrier. Structure allows for flow for majority of year.	**2**
Major modification from ideal	Obvious barrier, overflow is limited to times of high flow.	**1**
Extreme modification from ideal	Complete barrier, limited or no flow available for most of year.	**0**

2. Barrier location (sub-catchment ratios)

It is important to consider both the effectiveness of the barrier to influence hydrological connectivity and also its position within the catchment. The degree of naturalness for this parameter is related to the relative catchment areas upstream and downstream of the structure.

Table 5. Conditions and rating for barrier location.

		Rating
Excellent	Minor tributary or main channel within the upper catchment. Limited catchment area upstream - low order stream. Sub-catchment ratio >10%.	**4**
Good	Tributary or main channel within the upper catchment. Small catchment area upstream - low order stream. Sub-catchment ratio 10-25%	**3**
Moderate	Tributary or main channel. Low proportion of catchment area upstream of barrier. Medium order stream. Sub-catchment ratio 25-50%	**2**
Poor	Major proportion of main channel and/or high proportion of tributaries upstream of barrier. Moderate stream order. Sub-catchment ratio 51-75%	**1**
Very poor	Within the lower catchment on high order stream. Either main stream or tributaries (lower score for main channel). Sub-catchment ratio <75%	**0**

3. Fish passage potential

Barriers to fish passage are known to result in a decline in the diversity and abundance of fish communities. The indicators identify departures from a natural condition under which fish passage is not impeded.

Table 6. Conditions and rating for fish passage potential.

		Rating
Essentially ideal	Fish passage potential is essentially unaltered by the barrier present. This may be due to a fish passage device.	**4**
Near ideal	High potential for passage Little deviation from natural passage conditions.	**3**
Moderate modification from ideal	Moderate potential for passage. Temporal barrier for some of the year. Loss of production due to passage delay.	**2**
Major modification from ideal	Low potential for passage. Partial barrier. Blockage of the weaker and or smaller fish.	**1**
Extreme modification from ideal	Very low potential for passage. Nearly complete barrier, where only the strongest fish can pass or complete barrier.	**0**

4. Deviation of flow

Barriers alter the natural flow regime within the area they are located. The degree to which the flow is modified from natural conditions can be viewed in terms of upstream and downstream alterations. Typically upstream of a barrier water is impounded whilst downstream flow is restricted.

Table 7. Conditions and rating for deviation of flow.

		Rating
Essentially ideal	Essentially natural conditions of flow on either side of barrier.	**4**
Near ideal	Near natural flow downstream. Near natural conditions upstream of barrier. Minor impoundment and changes to flow regime.	**3**
Moderate modification from ideal	Flow partly restricted some reduction in wetted width. Alteration to volume and velocity of flow. Small impoundment area. Natural channel accounts for > 75% impoundment width. Increased depth obvious.	**2**
Major modification from ideal	Flow downstream obviously altered. Wetted width reduced. Small discharge volume with variable velocity. Replenish from output & tributary inputs. Moderate size impoundment. Natural channel width accounts for 75-25% of impoundment width. Depth moderate.	**1**
Extreme modification from ideal	Highly altered. Downstream no or extremely low flows (potentially high velocity). Relies on tributaries to replenish flows. Large impoundment area. Natural channel accounts for >25% of impoundment width. Highly modified depth.	**0**

5. Other in-stream barriers

This parameter relates the ability of other in-stream structures to effect the barrier being reviewed and highlights the impact of multiple developments for particular reaches.

Table 8. Conditions and rating for other in-stream barriers.

		Rating
Essentially ideal	Essentially unaffected by other barriers within the system.	**4**
Near ideal	Few structures natural or artificial influencing this point that act as fish barriers.	**3**
Moderate modification from ideal	Some barriers. For tributaries there may be no other barrier present on the tributary itself though present nearby on main channel.	**2**
Major modification from ideal	Several barriers affect this reach. Tributaries - at least one other barrier on same tributary.	**1**
Extreme modification from ideal	Multiple barriers affect this reach..	**0**

6. Bank stability

The stability of the surrounding stream banks is an important factor to determine in relation to hydrological connectivity. Stable conditions have been set as the standard for naturalness.

Table 9. Conditions and rating for bank stability.

		Rating
Stable	Erosion resistant soils; no undermining; usually gentle batter; good vegetative cover; no significant damage to bank structure or vegetation; no exposed roots.	**4**
Limited erosion	Good vegetative cover; some minor isolated erosion; no continuous damage to bank structure or vegetation, some exposed roots.	**3**
Moderate erosion	Banks held by discontinuous vegetation; some obvious damage to bank structure and vegetation; generally stable toe, moderate exposure of roots.	**2**
Extensive erosion	Little effective vegetation; mostly unstable toe; large numbers of exposed roots.	**1**
Extreme erosion	Evidence of unchecked rapid erosion; no effective vegetation; unstable toe; very recent bank movement.	**0**

7. Overall disturbance

This parameter allows for the determination of riparian condition around the barrier of interest. The riparian habitat plays an important role in maintaining the quality and ecological integrity of a waterway.

Table 10. Conditions and rating for overall disturbance.

		Rating
Essentially ideal	*Low Disturbance.* Native vegetation dominant, exotic species insignificant. Representative of pristine condition.	**4**
Near ideal	Native vegetation dominant on both sides. Few introduced species present. Any disturbance is minor.	**3**
Moderate modification from ideal	*Moderate disturbance.* Native species in reasonable numbers, the intrusion of introduced species is minor and of moderate impact. Moderate stock access.	**2**
Major modification from ideal	*Major Disturbance.* Riparian zone is modified. Native vegetation severly altered on one or more banks. Exotic species prolific. Disturbance from stock access evident.	**1**
Extreme modification from ideal	*Extreme Disturbance.* Riparian zone absent or severly reduced. If present native species rare, exotics dominant. cleared both banks. Unrestricted stock access and severe disturbance.	**0**

Analysis of all parameters provides an overall rating of how an individual barrier effects hydrological connectivity. In order to determine the effects of multiple barriers upon the system a decision tree was developed based on the aforementioned parameters. An overview of the decision tree is provided in Figure 2.

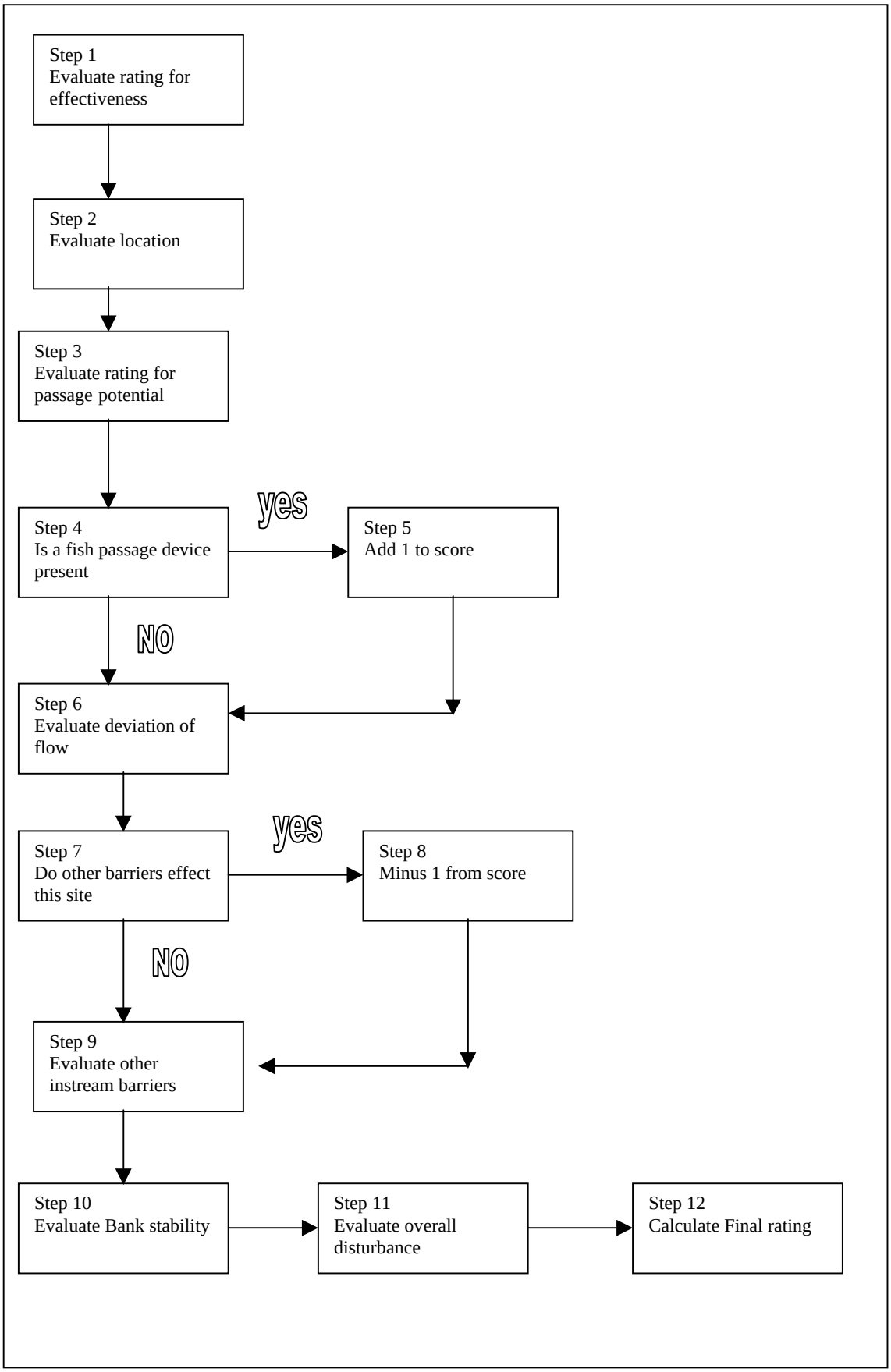

Figure 2: Procedure for calculating hydrological connectivity

4. RESULTS

Results of the IRC assessment of "Physical form" and "Stream-side zone" for the Duck River catchment are presented for the main channel, tributaries and for the catchment as a whole in Table 11.

Table 11. IRC sub-index values for the Duck catchment.

	Numerical value (Rating)		
Category	**Mainstream Duck R. Sites**	**Duck River tributaries**	**Average for all catchment sites**
Physical form	7.19	6.55	6.74 (Good)
Stream-side zone	3.59	3.55	3.56 (Poor)

It should be noted that "Hydrological connectivity" will be discussed separately due to the fact that not all barriers assessed coincided with actual site locations and therefore need to be addressed independently.

4.1 Results for the Duck River mainstream sites

A total of ten sites were sampled on the main-stream (Figure 1) and Index of River condition ratings for the Duck River main-stream are provided in Figure 3. Parameters that suggest major or extreme modification from a natural or ideal condition are presented in Appendix 3 along with any data gaps. Descriptive maps for Physical form and Stream-side zone sub-indices values are provided in Figures 5 and 6 respectively.

4.1.1 Physical form

The physical condition of sites surveyed on the mainstream showed an average rating of 7.19 (Table 11) or 'good' which indicated that the majority of sites were in near natural condition (Figure 5). As expected, the sites in the upper reach of the catchment rated as 'excellent' (ie. Duck at Wedge Plains Rd. (DUCK10), Duck at Maguires Rd. (DUCK09) and Duck at Trowutta Rd. (DUCK08)).

The physical form index dropped to the next rating as near natural or 'good' for the two mainstream sites, Duck at Poilinna Rd. (DUCK06) and Duck off Brodies Rd. (DUCK07). In the middle reaches, the physical form index dropped further to a 'moderate' rating indicating some modification from natural conditions. These sites included Duck at Trowutta upstream of Geales Creek (DUCK03), Duck at Lades Rd. (DUCK04) and Duck at Huetts Rd. (DUCK05). The lower catchment sites Duck at Bass Highway (DUCK01) and Duck at Kubanks Rd. (DUCK02) both showed an increase in physical form rating to 'good' or near natural condition.

It is evident from the assessments that major or extreme modification of individual physical form parameters occurs within agricultural and/or urban reaches of the Duck mainstream. In the lower catchment the indicators for Overall Site Disturbance (OSD) and Coarse Woody Debris (CWD) were extremely modified for sites DUCK01 and DUCK03, which occur within rural and urban areas. These indicators were also extremely modified for DUCK05, which is situated within agricultural reaches along Huetts Road.

4.1.2 Stream-side zone

The stream side zone index clearly stood out as the most modified of both sub-indices as illustrated in Figure 3 and this was reflected by the average stream-side zone sub-index rating of 3.59 (Table 11) indicating 'poor' conditions for the main stream sites. The condition of stream-side vegetation in the mainstream varied between reaches and like physical form ratings, reflected adjacent land use practices. In agricultural and urban areas there was a trend for reduced ratings, indicating a high degree of modification from natural conditions. This was highlighted in the lower catchment where sites, DUCK01 (Duck at Bass Highway) and DUCK03 (Duck at Trowutta u/s Geales Creek) rated as in 'very poor' condition, and DUCK02 (Duck at Kubanks Rd.) rated as in 'poor' condition.

Major modification to the stream-side zone was evident through the middle reaches of the main stream extending from sites DUCK04 to DUCK07. Conditions were 'very poor' at both DUCK06 (DUCK at Poilinna Rd.) and DUCK07 (Duck off Brodies Rd.) with these sites having stream-side ratings of 1.59 and 1.63 respectively. Both of these sites had extensive weed infestations, little to no riparian zones and unrestricted stock access to the river. While sites DUCK04 (Duck at Lades Rd) and DUCK05 (Duck at Huetts Rd.) had improved ratings of 3.80 and 3.43 respectively, which was also reflected by an improvement in the riparian zone encompassing the structural intactness, percentage of indigenous species present and amount of regeneration of those species.

The upper three sites (DUCK08, DUCK09 and DUCK10) on the mainstream all showed increasing improvement in their stream-side ratings with values of 4.15 (moderate), 7.34 (good) and 8.59 (excellent) scored respectively. Both Duck at Trowutta Rd (DUCK08) and Duck at Maguires Rd. (DUCK09) sites had significant modification to the longitudinal continuity of the riparian zones and stream side cover. The Duck at Wedge Plains Rd. (DUCK10) site showed little to no modification of the stream side zone, with indigenous species present and regenerating in reasonable numbers.

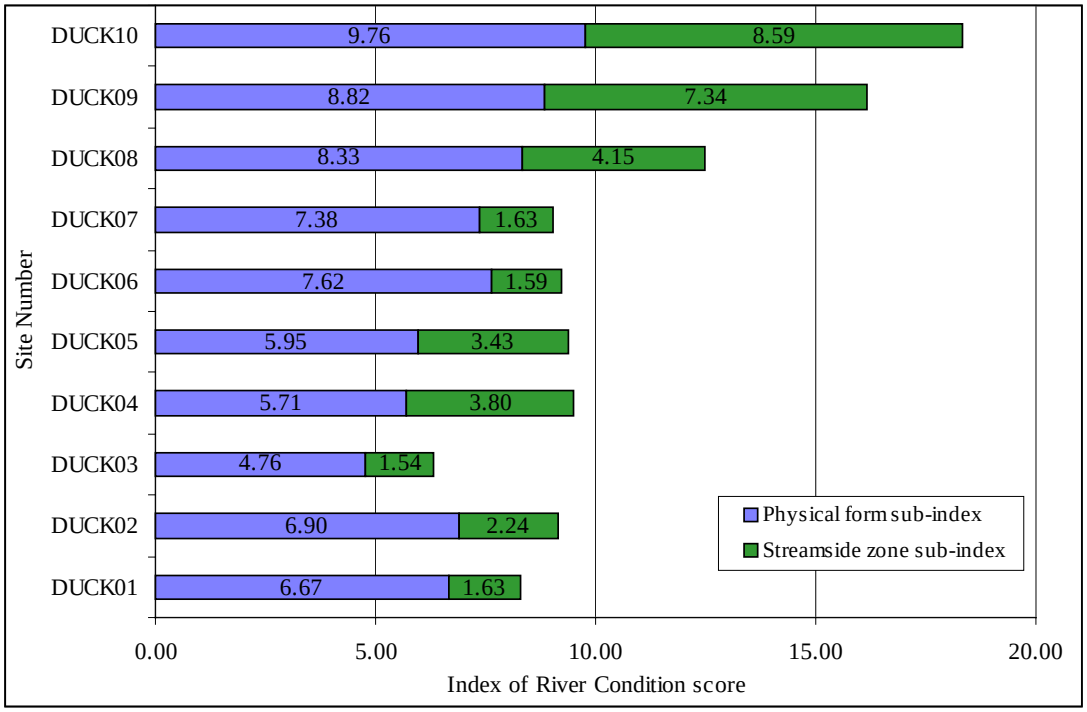

Figure 3. IRC results showing physical form and stream-side zone sub-indices for the Duck River main-stream sites (DUCK01 being the most downstream site).

4.2 Results for the Duck River tributary sites

A total of twenty-four sites were sampled on twelve tributaries (Figure 1). IRC ratings for the tributary streams of the Duck catchment are provided in Figure 4. Parameters that suggest 'major' or 'extreme' modification from a natural condition are highlighted in Appendix 3 along with data gaps. Descriptive maps for Physical form and Stream-side sub-indices values are provided in Figures 5 and 6 respectively.

4.2.1 Physical form

The average physical form sub-index rating for the Duck River tributary sites was 6.55 (Table 11), which is described as being in 'good' condition (near natural). Several tributaries had multiple sites surveyed along their entire length and while few of these showed a trend of improved river condition with distance upstream, some displayed a clear improvement between the most downstream site and the uppermost site surveyed. Roger River improved from 'moderate' condition having some modification at DUCK27 (Roger River at Roger River Rd.) to 'excellent' condition at the two upper sites sampled (DUCK28 and DUCK29). Similarly the rating for Birthday Creek at the lower site (DUCK22) was in 'poor' condition, having major physical form modifications, but was found to be in 'excellent' condition at the upper site (DUCK23). Multiple sites were sampled on Geales Creek and Edith Creek and both of these tributaries showed variation in their condition along the entire reach investigated. However both of these creeks showed an improvement in condition between the lower most sites and the upper most sites surveyed. For instance, Geales Creek at Trowutta Road (DUCK12) and Edith Creek at Huetts Road (DUCK17) were rated as in 'moderate' condition which equated to having some modification. The upper most sites, Geales Creek at Fagans Road (DUCK14) and Edith Creek at Lovetts Road (DUCK21) were found to be in 'good' condition or near natural. Typically ratings were higher in reaches where adjacent land usage was minimal.

The physical form sub-index varied in its rating for tributaries on which a single site was selected from 'moderate' to 'excellent' condition. As with the mainstream, physical form condition deteriorated in agricultural and urban areas. Coventry Creek (DUCK11) and White Water Creek sites (DUCK24 & DUCK25) rated as in 'moderate' condition due to urban and agricultural influences respectively. Near natural conditions were recorded for Copper Creek (DUCK15), Allen Creek (DUCK16), Faheys Creek (DUCK33) and Lairds Creek (DUCK34) which were all situated within partially developed agricultural zones. Mill Creek at Malompto Rd (DUCK26) occurs within native bushland and was found to rate as in 'excellent' or essentially natural condition.

4.2.2 Stream-side zone

The stream-side zone index clearly stood out as the most modified (Figure 4) and this was reflected by the average stream-side zone sub-index rating of 3.55 (Table 11) indicating 'poor' conditions for most Duck River tributary sites. While individual site ratings varied from 'very poor' to 'excellent' as with the physical form, sub-index general trends indicated a relationship between site condition to position within the sub-catchment and surrounding land usage. As was observed with the mainstream sites, the tributary sites that were located within agricultural and urban areas displayed a trend for reduced ratings, indicating a high degree of modification of the stream side zone from natural conditions.

Several tributaries had multiple sites surveyed along their entire length and while few of these showed a trend of improved river condition with distance upstream, some displayed a clear improvement between the most downstream site and the uppermost site surveyed. The Roger River lower site (DUCK27) had a 'very poor' stream-side rating (1.30), however the upper two sites (DUCK28 & DUCK29) had 'excellent' ratings of 8.29 and 8.85 respectively. The same results were found for the sites on White Water Creek and Birthday Creek, where the downstream sites (DUCK25 and DUCK22) both rated 'very poor' (0.38 each), while the upstream sites (DUCK24 and DUCK23) had an 'excellent' stream-side rating of 8.65 and a 'moderate' rating of 4.46 respectively.

All other tributaries where multiple sites were sampled showed variations in stream-side ratings along the reaches sampled, but generally the most downstream site was rated lower than the most upstream site. This was found for Geales Creek where the most downstream site (DUCK12) had a 'poor' rating of 2.07 which decreased in condition at the next site (DUCK13) to a 'very poor' rating of 0.38, but then improved at the uppermost site (DUCK14) to a 'moderate' rating of 4.26.

Edith Creek stream-side zone ratings also reflected a similar pattern of following land use changes along the reaches assessed. The two most downstream Edith Creek sites (DUCK17 & DUCK18) both occurred in agricultural areas where vast land clearing has occurred and this was reflected in the 'very poor' ratings of 0.38 at each site. The next site (DUCK19) occurred within an area where land use was limited allowing the stream-side zone to be left largely intact and the rating was therefore found to be 'good' (7.56). The last two uppermost sites on Edith Creek (DUCK20 & DUCK21) fell within areas of agricultural activity again and this was reflected in the ratings indicating that modification to the stream-side zone had occurred giving a 'poor' rating of 2.16 and a 'moderate' rating of 4.79 respectively.

Spinks Creek was an exception where the most upstream site did not show any improvement in stream-side condition from the most downstream site. This was due to the fact that both of these sites (DUCK30 & DUCK32) occurred in areas of intensive agricultural land use and the resulting ratings were 'very poor' (1.92 & 0.38 respectively). The middle site on this creek (DUCK31) was located in a pocket of untouched forest, accounting for an 'excellent' rating of 8.94 between sites upstream and downstream with a 'poor' rating.

The stream-side zone sub-index varied in its rating for tributaries on which a single site was selected from 'very poor', displaying high modification to 'excellent' being in essentially natural condition. As with the mainstream, stream-side zone condition deteriorated in agricultural and urban areas where land use has resulted in the clearing of tracts of native vegetation. Coventry Creek (DUCK11), Allen Creek (DUCK16) and Faheys Creek (DUCK33) sites rated as in 'very poor' condition (1.68, 0.38 & 1.99 respectively) due to urban and agricultural influences. 'Poor' conditions or major modification to the stream-side zone were recorded for Copper Creek (DUCK15) and Lairds Creek (DUCK34) which were both situated within partly developed agricultural zones. The Mill Creek site (DUCK26) occurs within native bushland and was found to rate as in 'excellent' or essentially natural condition.

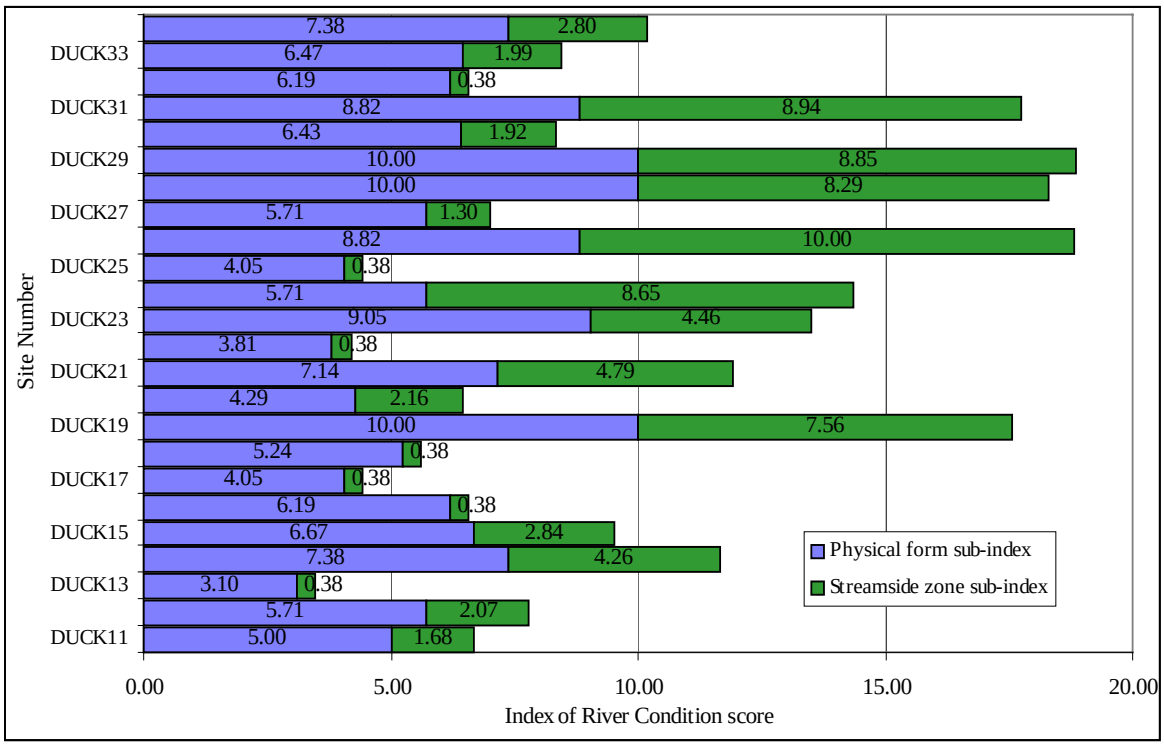

Figure 4. IRC results showing physical form and stream-side zone sub-indices for the Duck River tributaries (DUCK11 being the most downstream site and DUCK34 being the upper most site).

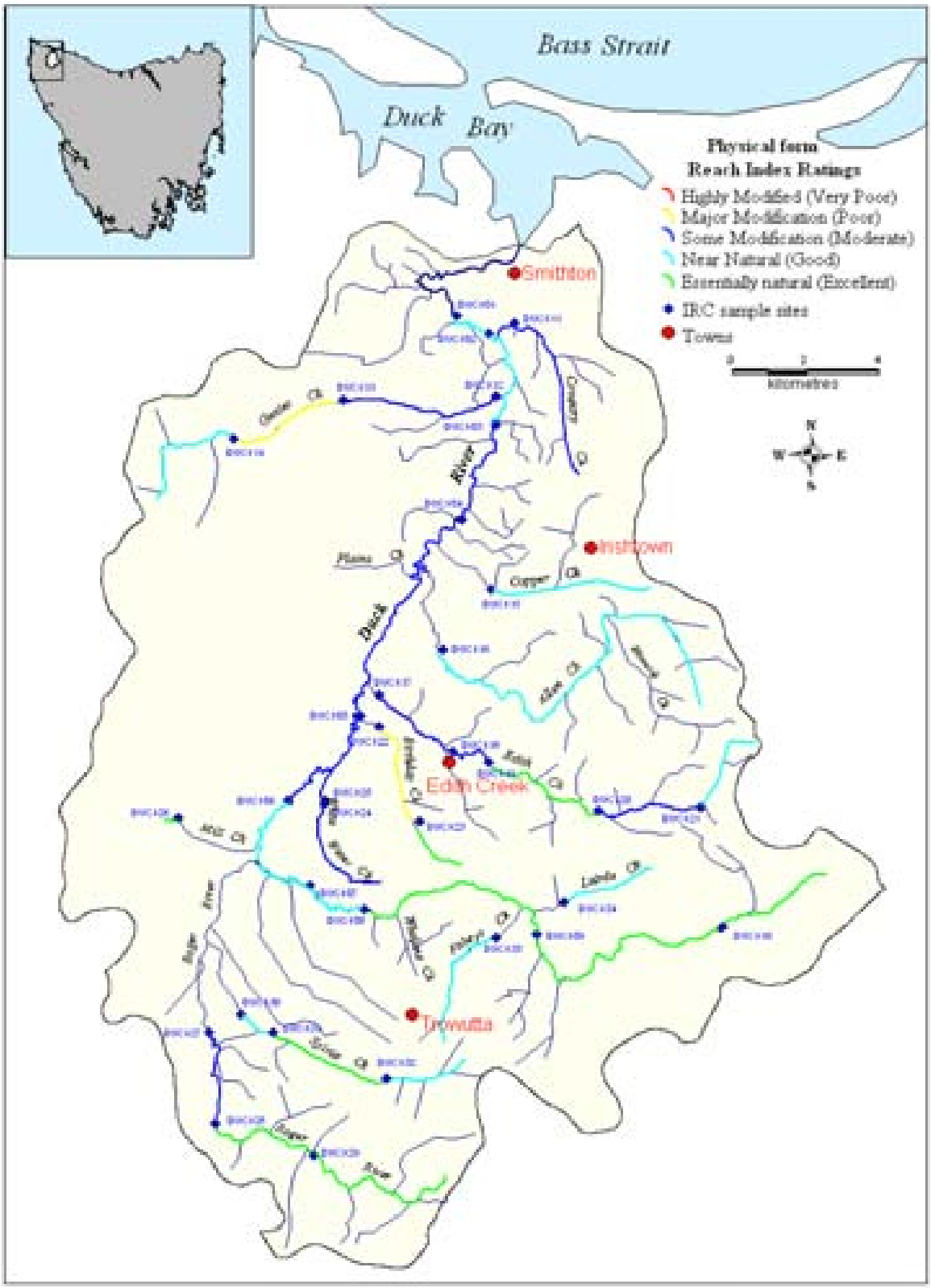

Figure 5. Map showing physical form sub-index ratings for each site reach in the Duck river catchment.

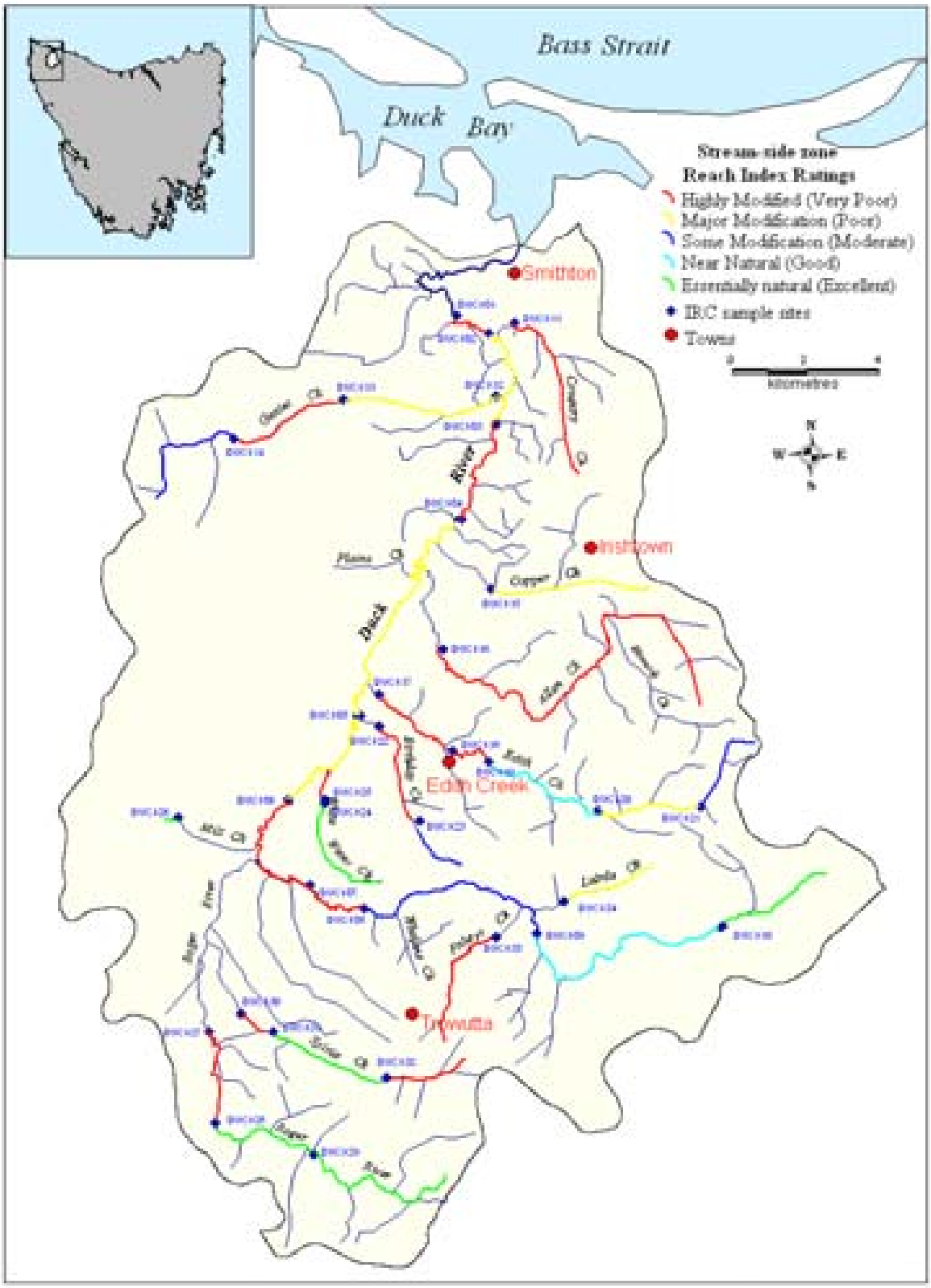

Figure 6. Map showing stream-side zone sub-index ratings for each site reach in the Duck River catchment.

4.3 Hydrological Connectivity

Results of the hydrological connectivity assessment for the Duck River catchment are presented for the main channel, tributaries and for the catchment as a whole in Table 12.

Table 12. Hydrological connectivity values for the Duck catchment.

	Numerical value (Rating)		
Category	**Main-stream Duck R.**	**Duck River Tributaries**	**Average for all catchment**
Hydrological connectivity	7.96	6.23	6.61 (Good/Near ideal)

Forty-six in-stream structures were assessed within the catchment to determine their potential effect on fish movement. Figure 8 shows the distribution of structures and related fish passage values of structures that were surveyed within the catchment. Twelve of these structures were identified as providing 'moderate' to 'extreme' barriers to fish passage and an overview of these barriers of concern is given in Table 13. The location, type and rating for all barriers surveyed for the catchment are provided in Appendix 4.

Culverts and dams within the catchment tend to be situated on minor tributaries or tributaries of major streams draining into the main channel. Those structures situated on small tributaries contain small sub-catchment areas upstream and as such represent a small proportion of the overall habitat available within the catchment. As a result they are likely to have little effect on fish passage in relation to the catchment as a whole.

Table 13. In-stream structures rated as 'moderate' to 'extreme' barriers to fish passage.

No.	**Barrier location**	**Easting**	**Northing**	**Type**	**Rating**
32	Edith Creek at Lovetts Road	346600	5461500	Dam	Extreme
44	Faheys Creek at Maguires Road.	339800	5457150	Culvert	Major
26	Blizzards Creek at South Road	345400	5464100	Dam	Major
45	Faheys Creek at Maguires Road	340000	5457200	Dam	Major
11	Unnamed trib, lower catchment at Mella Rd	337200	5476300	Culvert	Moderate
12	Unnamed trib, lower catchment at Mella Rd	337100	5476200	Culvert	Moderate
14	Coventry Creek at Connel Cross Road	342800	5471800	Culvert	Moderate
16	Geales Creek at Bass Highway (DUCK13)	336700	5473100	Culvert	Moderate
18	Geales Creek at Fagans Road	333500	5472300	Culvert	Moderate
27	Blizzards Creek at South Road	345300	5464100	Culvert	Moderate
31	Edith Creek at Lovetts Road (DUCK21)	346600	5461500	Culvert	Moderate
42	Greenes Creek at Roger River Road	335520	5456830	Culvert	Moderate

Of the in-stream structures surveyed only one weir was found on the mainstream (see Appendix 4) and while under low flows this structure could potentially pose a barrier to fish movement, the Inland Fisheries Service has recently improved the fish passage potential by installing a rock ramp. The presence of this fish passage device and the distribution of fish throughout the reaches of the catchment upstream from the weir would also indicate that the barrier threat that the weir previously posed has been reduced.

The hydrological connectivity ratings for the total number of on-stream dams for the whole Duck catchment were not investigated due to their large number (189). However in the

absence of any fish ladder or fish passage device those dams that were identified were found to have the greatest effect on overall fish movement.

Figure 7 presents the average ratings for various types of structures investigated in relation to hydrological connectivity in the Duck catchment. Essentially, bridges result in 'partially modified' conditions, culverts result in 'moderately' altered conditions and farm dams result in 'poor' conditions for fish passage. Only one weir was located within the catchment and this was found to provide 'partial modification' for fish passage. As on-stream storages are almost exclusively located on associated tributaries, smaller order streams provide only 'moderate' condition for passage.

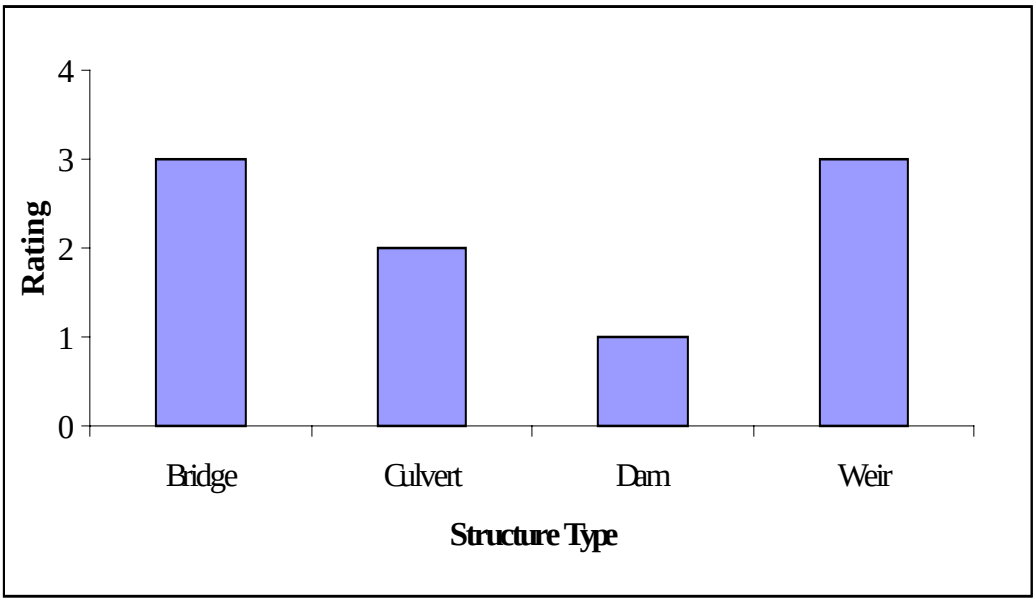

Figure 7. Median rating values for different barrier types assessed within the Duck catchment.

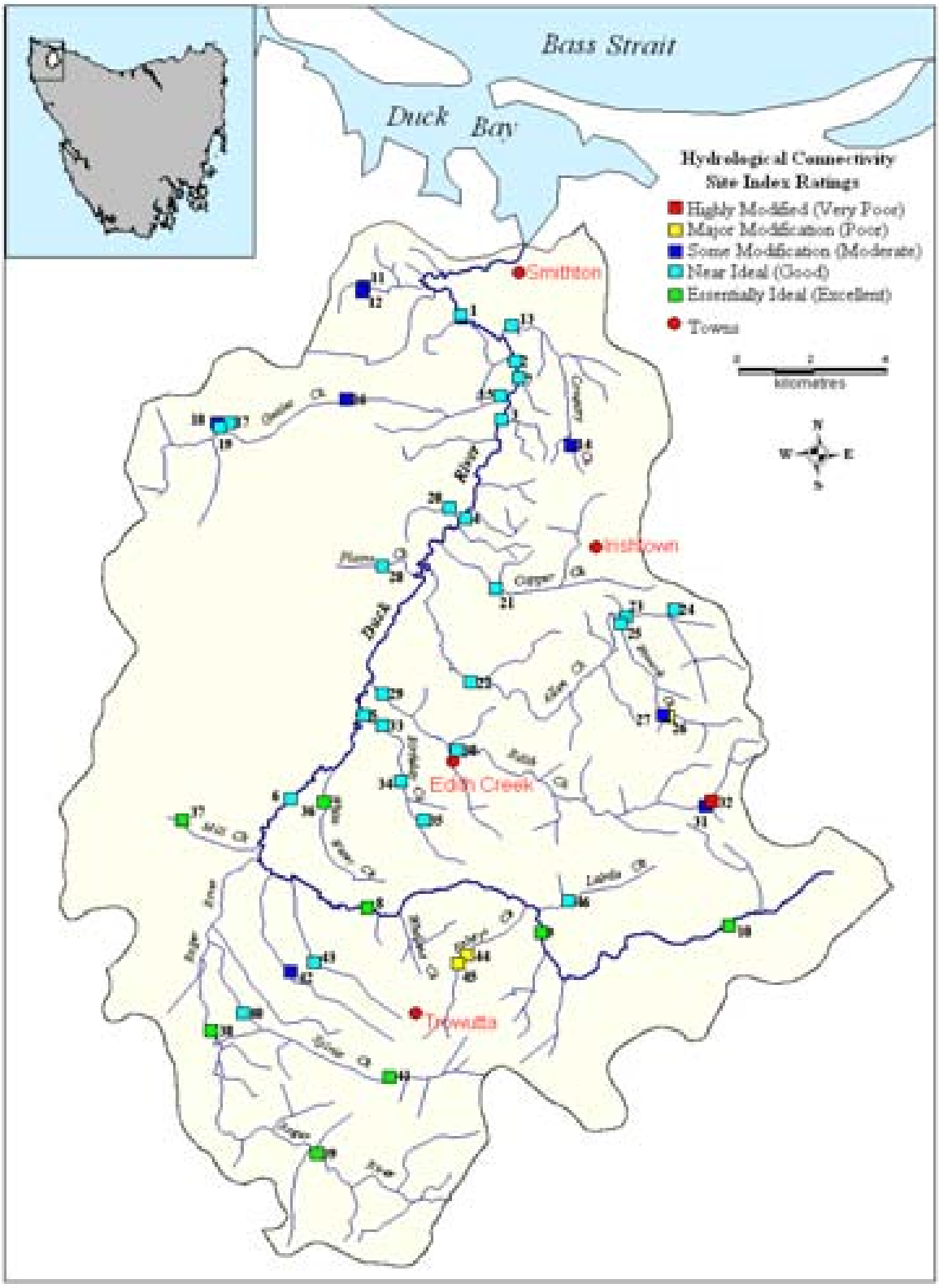

Figure 8. Map showing hydrological connectivity ratings for each site assessed in the Duck River catchment.

5. DISCUSSION

Physical River Condition and Stream Side Zones

The variable nature of the IRC ratings for both physical condition and the stream-side zones of reaches surveyed reflects the diverse nature of land use in the Duck River catchment. The comparatively undisturbed condition of the stream-side zone and physical condition of reaches is evident in the upper most reaches surveyed on the Duck River mainstream. It is clear however from the information collected that the index scores of some sites within the catchment vary away from a 'near natural' state to 'moderate' or 'poor' condition for either or both indices. Management issues throughout the sites surveyed within the Duck River catchment have been identified in relation to 'poor' ratings for physical form and stream-side zone and are provided in Appendix 6.

There was a general trend for an improvement in river condition in an upstream direction for tributaries on which multiple sites were surveyed. This is clearly shown in the Birthday Creek, White Water Creek and Roger River catchments where both index ratings showed an improvement between the lower and the upper sites. However Geales Creek, Edith Creek and Spinks Creek did not follow this trend as they were similarly influenced by adjacent land usage practices at the lower and upper sites.

The most predominant factors influencing site condition throughout the catchment were the presence of a variety of exotic species in the stream-side zone. Introduced species such as Crack Willow (*Salix fragilis)*, blackberries (*Rubus fruticosus)*, ragwort (*Senecio jacobaea)* and thistles (*Cirsium vulgare*) were found to be well established in certain sections of the Duck River and many of its tributaries. Blackberries were surveyed in the stream-side zone at twenty-two of the thirty-four sites assessed. Many exotic species commonly found along riverbanks in Tasmania are early colonising species with high reproductive rates and rapid dispersal capabilities (Read, 1999). Such species are well adapted to colonising areas where riparian disturbance has occurred. The prolific growth of weed species can be inhibitory to the growth of native species within the riparian zone (CEAH, 1997b). For example, intense shading by willow tree canopies can inhibit the light environment suitable for the growth of seedlings of many native species (Read, 1999). In addition, the presence of pasture grass and other weeds does not provide the deep soil-root matrix required to support the river embankment, particularly from the effects of erosion (Abernethy and Rutherford, 2000).

It was also noted that at many sites stock have unrestricted access to stream banks. This frequently creates excessive bank erosion and may lead to increased sediment load into a watercourse. In-stream siltation also has the potential to be a management issue due to upstream land usage from forestry operations and from lack of riparian buffer zones. Settling of sediment on the streambed and the shift from hard to soft substrate can have a long-term deleterious impact on benthic fauna (Taylor, 1991). The growth of weed species, such as willow can also be favoured by the shift in substrate composition (Suter, 1990). Willow trees of varying degrees of infestation also occur at nine of the thirty-four sites including four sites on the mainstream. The effects of willows, if they become too well established, include:

- Altered runoff patterns due to a lack of understorey (Collier *et al*, 1995);
- Altered in-stream habitat (Read and Barmuta, 1999);
- Inhibition of primary production through reduced light penetration (Nelson, 1999);
- Increased sedimentation and organic load - nutrient increases (Suter, 1990), and
- Reduced low flows - decreased dissolved oxygen levels (Bobbi, 1999).

Generally sites located within agricultural and urban areas usually lacked riparian vegetation. The stream-side zone is the interface between the aquatic and terrestrial environment and acts as an important buffer to any activities that may occur in the adjacent land zone. Riparian vegetation of appropriate buffer widths and complexity can provide significant protection for streams via the mechanisms below:

- Protection from sediment run-off from forestry, farming or road building activities (Collier *et al*, 1995);
- It may act as a filter to chemical spray from intensive agriculture or forestry (Davies *et al.,* 1994);
- It provides bank-side stability and inhibits erosion (Abernethy and Rutherford, 1999);
- It forms an important relationship with aquatic systems by providing in-stream and bank-side habitat for fauna (Stevens and Cummins, 1999);
- It is the source of nutrient inputs through snags and leaf fall (Stevens and Cummins, 1999);
- It reduces water temperature through shading effects (Collier *et al.*, 1995), and
- Continuous vegetation is important as faunal corridors and in maintaining suitable habitat (Stevens and Cummins, 1999).

Hydrological Connectivity

The location of a barrier within a catchment can influence its impact on fish populations. Where the catchment area upstream of a barrier is small, the proportion of upstream habitat in relation to the whole catchment is low. In such instances even a complete barrier may isolate only a small proportion of a catchment and prevent fish populations from travelling past it. As a result, the impacts in relation to the whole catchment are comparatively small. In contrast, barriers to fish migration in the lower reaches of a system have the potential to cause the greatest effect on fish recruitment and distribution upstream. The cumulative effect of barriers along a river may result in populations becoming reduced, even when individual barriers have a low effect on movement.

Many of the minor tributaries in the Duck catchment have on-stream dams, which have a cumulative effect on hydrological connectivity. This has implications for fish passage as movement is limited by the low availability of water, which in turn reduces the availability of in-stream habitat under these low flow conditions. Changes to flow regimes in regulated rivers have been identified as a factor influencing fish passage (Mallen-Cooper, 2000). The majority of on-stream dams occur on tributaries throughout the catchment (illustrated in Figure 9). As a result of this type of development the hydrological connectivity on these smaller rivers and streams are likely to be further fragmented. This means dams will exert the greatest effect on tributaries rather than the mainstream. The pattern of development has implications for the catchment in terms of fish movement management as several individual tributary systems have the potential to become hydrologically disconnected from the remainder of the catchment.

Similarly forestry operations within an area are often likely to lead to an increase in the number of minor road crossings within a tributary. Typically, crossings of minor streams incorporate elements, such as culverts into their design. When such crossings are poorly constructed (eg: a perched culvert) the altered flow regime impacts upon hydrological connectivity and habitat availability for fish species.

Dissimilarities often occur in relation to fish community composition on either side of a physical structure and the degree of dissimilarity is largely a function of how effective the barrier is to preventing passage. Barrier effectiveness is also partly determined by any fish species ability to migrate past it. For example, species such as the short-finned eel (*Anquilla australis*) which can move across land and the climbing galaxias (*Galaxias brevipinnis*)

which can climb steep gradients, are able to negotiate barriers more easily than those species that rely purely on swimming such as the jollytail (*Galaxias maculatus*). This is evident in Figure 9, where the location of fish species found in the catchment has been overlayed on a map showing dam locations, to give a visual presentation of the effect that on-stream structures have on the movement of fish.

Overall, fish passage and hydrological connectivity for the Duck River catchment was found to range in condition from 'good' to 'extremely modified'. In addition to artificial structures such as weirs, farm dams, culverts, and road crossings that have the potential to act as physical barriers, less tangible physical and behavioural barriers are also likely to affect fish movement within the system. For instance erosion control, willow removal and other kinds of in-stream works can act as temporary barriers to fish movement during operations and depending on the degree of disturbance may prevent fish movement for a period of time after works have been completed.

Physical disturbance of the in-stream environment may evoke a behavioural response as a result of changes to water quality parameters. Behavioural barriers arise when changes to the aquatic environment affect fish physiology and result in individuals avoiding conditions that can cause physiological stresses (Thorncraft and Harris, 2000; Mallen-Cooper, 2000). Such changes may include low oxygen levels, high turbidity, high nutrient loads and reduced flow. These changes have the potential to affect fish physiology and movement. As adverse conditions may be inadvertently created during in-stream rehabilitation works, the timing of river management activities taking into consideration the requirements of migrating fish species and periods of peak fish movement (e.g. spawning migration) are important when planning river restoration activities.

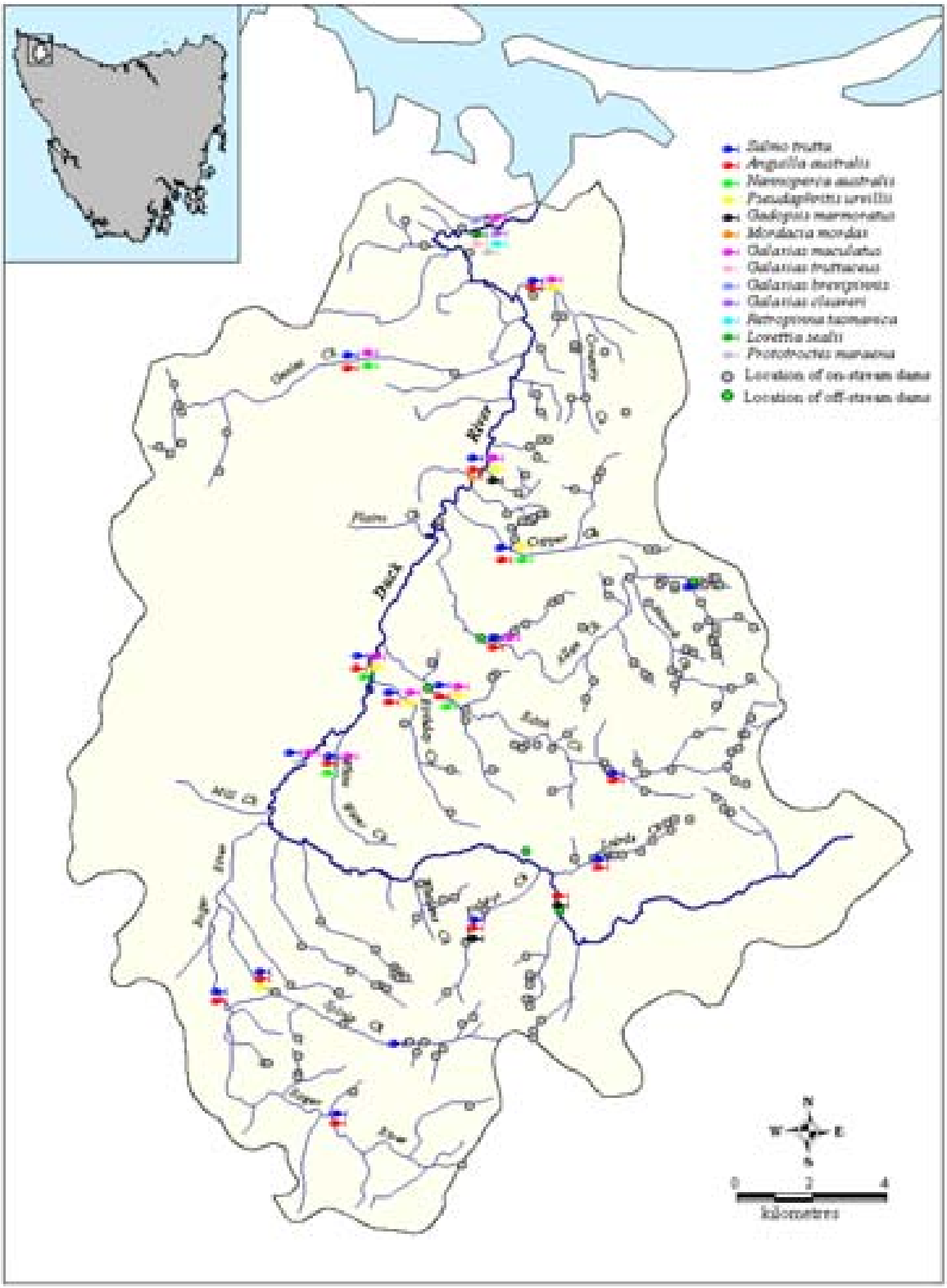

Figure 9. Map showing distribution of fish species and location of all on- and off-stream dams in the Duck River catchment (as listed in the WIMS database as at October 2002).

Main-stream Duck River

The IRC assessment indicates that the sites on the mainstream Duck River display varying degrees of departure from a natural condition. It is evident that some impacts are related to adjacent agricultural and urban land use practices. Stream side zone conditions at each site are also influenced by the presence of non-native species in the stream-side zone, principally Crack Willow, thistles and blackberries.

Physical form rated as in 'good' condition overall, while the condition of the stream-side zone was significantly more impacted with an average stream-side zone condition rated as in 'poor' condition, particularly in the lower and middle sections of the catchment.

Specific management issues identified for the mainstream Duck River sites are provided in Appendix 6. Management issues that may be considered include the presence of crack willow at four of the ten sites (effectively throughout the lower and middle mainstream reaches), the presence of understorey weed species such as blackberries and thistles, reduced riparian zones at most sites, stock access and resultant bankside erosion at a number of sites. In summary, most of the critical problems for the mainstream occur in the stream-side zone where ratings are low.

The hydrological connectivity of the mainstream was found to be from 'near' to 'essentially ideal' with only the Duck River weir providing any potential problem for fish passage under low flows. The open structure of the weir allows for drowning out throughout the majority of the year and more recently with the modification of the weir to incorporate a rock ramp, the structure is likely to provide little impediment to fish passage. Any delay in passage are likely to be due to various species having to locate the device, however it was beyond the scope of this study to determine passage rates for fish species through this structure.

Of the twenty-five species of native freshwater fish in Tasmania, eleven are known to have migratory components to their lifecycles (Fulton, 1990). However, all fish species require access to preferred habitat that requires movement and colonisation over varying distances depending on territoriality and this varies between species. There are ten native fish species that have been recorded from the Duck catchment that require unimpeded passage between the lower reaches and headwaters. Fish are frequently denied access to areas upstream of physical barriers (Walker, 1999) and in many instances habitat present in these upstream reaches (eg; spawning sites on gravel beds) are essential for the completion of the fishes life history.

Analysis of fish distribution records (Inland Fisheries Services database and DPIWE database) shows that there is a general trend for native species diversity and abundance to reduce with distance upstream in the Duck River catchment (Figure 9). Davies (1989) found that Tasmanian rivers naturally tend to have a higher diversity and abundance of native species such as galaxiids etc., closer to the sea, but are dominated by brown trout and eels through the middle to upper reaches. This was reflected in the records of locations of fish species through the main channel of the Duck River (Figure 9). However, it would appear that throughout the tributaries where large numbers of on-stream dams are present, fish distribution is being influenced by the presence of these structures.

Seven native fish species occur upstream of the Duck River weir (see Figure 9) and these are the short-finned eel (*A. australis*), the jollytail (*G. maculatus*), the sandy flathead (*P. urvillii*), the river blackfish (*Gadopsis marmoratus*), the short-headed lamprey (*Mordacia mordax*), Australian grayling (*Prototroctes maraena*) and the pygmy perch (*Nannoperca australis*). Pygmy perch and river blackfish are both non-migratory, however pygmy perch also occur below the Duck River weir. *Anguilla australis* are capable of climbing and or movement across moist surfaces (Walker, 1999) and therefore it is unlikely that populations

would be affected by the weir. A single short-headed lamprey record is known upstream of the weir suggesting potentially poor conditions of passage for this species.

If passage across an in-stream barrier is not favourable for different species, there is the potential for genetically distinct populations to arise. This has ramifications for genetic diversity with the potential to lower the populations' ability to adapt to changes in environmental conditions (Walker, 1999).

Tributaries of the Duck River

Tributary streams in the Duck River catchment were found to be impacted by adjacent land use practices such as grazing and cropping, urbanisation (in certain areas) and to a lesser extent forestry, in a similar fashion to mainstream sites. Generally physical form rated as in 'good' condition whilst stream-side zones were rated as in 'poor' condition. These results indicate that the overall river condition of tributary reaches was heavily influenced by modifications to the stream-side zone from riparian practices. General issues and impacts for tributaries overall include the following:

- Stream bank erosion due to the lack of stream-side zones.
- Uncontrolled stock access to stream banks.
- Presence of exotic plant species.
- Limited indigenous plant regeneration.
- Lack of stream-side vegetation.
- Farming practices that limit riparian zones.
- Forestry practices including extensive plantations with no natural stream-side zones and limited understorey.

The most common disturbances to the riparian zones on tributaries were related to extensive weed infestation (crack willow and blackberries) or conversely, limited to no riparian vegetation. Stock access to stream banks was also identified as a significant impact. Specific management issues for each tributary study reach are provided in Appendix 6.

Overall the hydrological connectivity of the structures surveyed in the tributaries displayed some modification with the ratings for individual tributaries varying throughout the catchment. A general trend was noted for improving condition for hydrological connectivity for tributaries within the upper catchment.

Given the particular nature of disturbance to the river condition at each tributary site, details on site condition in relation to ratings for physical form, stream-side zone and hydrological connectivity are discussed below.

Coventry Creek (DUCK11)

The single site on this tributary was rated as in 'moderate' condition in respect to physical form and in 'very poor' condition in relation to the stream-side zone. In general, riparian vegetation health for Coventry Creek is very poor, with little to no riparian zone present along long stretches and sparse indigenous plant regeneration present. Excessive siltation and algal cover and unrestricted stock access were also evident for the site surveyed. Hydrological connectivity has been altered within this system through the presence of on-stream dams. However only two structures were assessed within the lower and upper sections of the creek (bridge and culvert respectively) and the results indicated that in the upper reaches of the tributary catchment, 'moderate modification' from ideal is occurring through the presence of a culvert. Water quality issues within this tributary influenced by leaching of pollutants from industry present adjacent to the creek and physical factors such as erosion may also influence the movement of fish into the tributary.

Geales Creek (DUCK12, DUCK13 & DUCK14)

The longitudinal pattern of river condition for this tributary indicates an improvement in the upper reaches of the catchment compared with the lower reaches, however the middle reach is clearly impacted by land use practices. The physical-form sub-index indicates 'moderate', 'poor' then 'good' conditions for the lower to upper sites respectively. Physical form indicators of 'bank condition', 'coarse woody debris' and 'overall site disturbance' highlight the major variation of the impacted sites from ideal conditions (see Appendix 3). The stream-side zone sub index rates the sites from 'poor' to 'very poor', then in 'moderate' condition from the lower to upper sites respectively. Virtually all stream-side zone indicators suggest major to extreme modification of condition with the exception of the upper site where only 'riparian width' and 'longitudinal continuity' is affected. Weeds such as thistles and blackberry dominate the limited riparian zone in the middle and lower reaches and indigenous plant regeneration is generally limited for the catchment. Extensive areas of erosion and siltation were also identified during the survey.

Hydrological connectivity for this system has been 'moderately' modified. Channel alteration is evident with multiple culverts and road crossings due to urbanisation and in-stream dams in the upper tributary catchment. Poor water quality (refer to Duck River Water Quality report) and physical factors such as erosion and excessive siltation are likely to be a potential impediment for fish movement within this tributary.

Copper Creek (DUCK15)

The physical form sub-index rated as 'good' or near natural for the site assessed on this tributary and of all physical form indicators, 'coarse woody debris' was the most modified from a natural state. The stream-side zone sub index conversely rates as 'poor' however, with 'riparian width', 'structural intactness' and 'longitudinal continuity' indicators displaying major or extreme modification from a natural condition (see Appendix 3). The poor stream-side zone rating is reflected by the sparse riparian zone, lack of indigenous plant regeneration and dominance of exotic species such as crack willow, blackberries, thistles and ragwort.

The hydrological connectivity of this system is largely unaffected by in-stream structures. While there are some on-stream dams present within areas of the upper tributary and drainage bodies, the bridge that was assessed was found to provide 'near ideal' conditions for fish passage.

Allen Creek (DUCK16)

The site assessed on Allen Creek was influenced by agricultural practices, which while having little influence on physical form rating strongly affected the stream-side zone rating. The physical form sub-index rated as 'good' with only the 'overall site disturbance' indicating major modification from natural condition (see Appendix 3). Whereas the stream-side zone rated as 'very poor' with all sub-index indicators highlighting major or extreme modification from natural condition. Management issues include the lack of riparian zone and lack of indigenous plant regeneration along with the unrestricted access by stock to the creek banks, excessive siltation present in-stream and presence of rubbish dumped in the creek.

The hydrological connectivity for the tributary rates as 'near ideal' with only bridges being assessed to provide adequate passage for fish species. However on-stream dams were not investigated within this tributary although there are a large number present and electrofishing

surveys have shown that passage upstream is being impeded due to the small number and diversity of species found in the upper reaches (see Figure2).

Edith Creek (DUCK17, DUCK18, DUCK19, DUCK20 & DUCK21)

Edith Creek is one of the major tributaries within the Duck River catchment and aside from the Duck River mainstream, contained the highest number of sites selected for assessment of river condition. It has been found that condition for all sub-indices typically reflects the intensity of surrounding land usage and this is evident from the results of each sub-index. The physical form sub index for the lower section rated as in 'moderate' condition, with the 'coarse woody debris' and 'overall site disturbance' indicators suggesting a major or extreme difference from a natural condition (see Appendix 3). The site within the middle section of the creek rated as in 'excellent' condition due to the low intensity of land use in this area, whereas the sites in the upper section of the creek rated as in 'moderate 'and in 'good' condition close to the source.

As with the general trend for all sites within the Duck catchment, the stream-side zone condition was rated as markedly worse than the physical form condition for sites in the Edith Creek sub-catchment. The lower reaches rated as 'very poor' with all sub-index indicators suggesting a major or extreme modification from a natural condition (see Appendix 3). The middle reach again rated as in 'good' or near natural condition due to the lack of modification to the riparian structure. The sites within the upper reaches rated poorly, indicating major modification from a natural condition, however this improved slightly with distance upstream to the source. Obvious management issues highlighted for this tributary include poor riparian structure, limited cover by native species, a high proportion of exotics (willow, blackberry, and thistles) along with stock damage to stream bank structure.

Hydrological connectivity is strongly affected by in-stream structures for this tributary. Once again while only bridges, a culvert and one dam was assessed there are large numbers of on-stream dams located throughout tributaries and the mainstream of this creek. The dam that was assessed was found to provide a significant barrier to the movement of fish. Although it was located high in the catchment and was therefore likely to have a limited overall effect from a whole of catchment perspective, it did highlight the impact that such in-stream structures have on fish passage. Aside from the dam assessed, the culvert was rated as a 'moderate' impact to fish movement through the limited ability to gain access through the structure during times of reduced natural flows.

Birthday Creek (DUCK22 & DUCK23)

The downstream site on Birthday Creek received one of the lowest physical form sub-index ratings for the entire Duck River catchment. The 'poor' rating indicated major modification from natural conditions with the 'coarse woody debris' and 'overall site disturbance' indicators being extremely impacted (see Appendix 3). In contrast the upstream site received an 'excellent' physical form rating indicating essentially natural conditions. The stream-side zone index reflected the same trend for both sites, with the downstream site being rated as 'very poor' and having all indicators subject to major or extreme modification. The upstream site received a 'moderate' rating for the stream-side zone, with only 'longitudinal continuity' and 'streamside cover' indicators highlighting some form of modification. The impacts found to be of importance within this tributary include poor riparian vegetation cover and continuity, unrestricted stock access to stream banks and spot erosion on the stream banks.

Hydrological connectivity for this tributary was found to be in 'good' or near ideal conditions for fish passage. Culverts were assessed and found to provide adequate potential for the movement of fish. There are few on-stream dams present within this tributary system

and due to their position high in the catchment and on minor water bodies, they would be unlikely to cause any major impact on the movement of fish through the Duck River catchment.

White Water Creek (DUCK24 & DUCK25)

The sites assessed on this tributary were found to rate in 'moderate' condition for the physical form sub-index. However the stream-side zone sub-index was found to be 'excellent' for the upstream site but was 'very poor' for the downstream site due to the total lack of riparian vegetation and stream-side structure. Management issues identified for this tributary include the erosion and channelisation of stream banks, the presence of blackberries and thistles, limited indigenous plant regeneration and stock access to riverbanks.

The hydrological connectivity for this tributary rated as 'essentially ideal' with the only bridge assessed as providing natural conditions for fish movement. There are currently no dams on this waterway and the presence of native fish provides evidence of the accessibility between the Duck River and this tributary.

Mill Creek (DUCK26)

Mill Creek is a small tributary located in the middle to upper reaches of the Duck River and land use is restricted to forestry in the uppermost reaches of it's catchment. The near natural conditions are reflected in the 'excellent' ratings determined for the physical form and stream-side zones.

Hydrological connectivity of this tributary is largely 'ideal' with no structural barriers identified that would cause any impediment to fish movement throughout the Duck River catchment.

Roger River (DUCK27, DUCK28 & DUCK29)

The Roger River catchment showed an improvement in IRC scores for both physical form and stream-side zone from the downstream to the upstream sites. The downstream site (DUCK27) received a physical form rating of 'moderate' indicating some modification, particularly with regards to the 'overall site disturbance' indicator (see Appendix 3). The stream-side zone rating for this site was 'very poor' with six out of the seven indicators suggesting an extreme to major modification to natural conditions. The middle and upstream sites received 'excellent' ratings both for physical form and for stream-side zone sub-indices. The management issues for the lower site include the presence of willows, blackberries and thistles, limited riparian width and poor indigenous plant cover. Unrestricted stock access has also been identified as a potential management issue. No specific management issues have been identified for the upper reach.

The hydrological connectivity of this tributary was rated as 'essentially ideal' due to the fact that only bridges were assessed and found to provide natural conditions for fish movement. While there are a few on-stream dams located within the Roger River catchment, these are present in the upper reaches of the main channel and water bodies draining into the river and as such should not pose any significant threat to fish passage.

Spinks Creek (DUCK30, DUCK31 & DUCK32)

Spinks Creek was another tributary whose IRC ratings reflected the influence of surrounding land use rather than displaying the trend of increased river condition with distance upstream. As a result, the downstream and upstream sites both had physical form and stream-side zone ratings of 'good' conditions and 'very poor' conditions respectively. These sites were

situated within agricultural areas where land use has impacted on the structure and extend of riparian vegetation and physical stream condition. Management issues that have been identified as a result of the survey include presence of weed species (willows, thistles, blackberries and ragwort), unrestricted stock access to riverbanks and severely reduced riparian zones. The middle site assessed was rated as having 'excellent' physical form and stream-side zones and this was largely because of the position of the site within an area of largely untouched native forest.

Hydrological connectivity for this tributary was similar to that of Roger River, with only bridges being assessed for fish passage potential. The results of the assessment indicated that conditions for fish movement are 'near ideal'. However there are on-stream dams located on the mainstream of this tributary that were not assessed for hydrological connectivity and in the absence of any appropriate fish ladder, these dams will prevent the movement of fish under low flow conditions.

Faheys Creek (DUCK33)

Physical form for this reach was rated in 'good' condition while the stream-side zone was rated as in 'very poor' condition indicating highly modified conditions from a natural state. Four of the seven indicators of the stream-side zone sub-index suggested major or extreme modification from natural conditions and this appeared to be largely due to the extensive land clearing associated with agricultural activities in the area (see Appendix 3). Management issues identified for this tributary include reduced riparian zone, presence of weeds such as blackberries, erosion and unrestricted stock access to river banks.

Two in-stream structures were identified that alter hydrological conditions from the source of the tributary to the confluence with the Duck River. Both the dam and culvert investigated rated poorly indicating a major modification from ideal for the movement of fish. While only three dams are present on this tributary, a lack of sufficient fish ladders has caused each water body to become hydrologically isolated under periods of low flows. Faheys Creek is not a large tributary and is situated high in the Duck River catchment, therefore although hydrological connectivity is far from ideal the impact on a whole of catchment level is relatively small.

Lairds Creek (DUCK34)

The physical form sub-index rated in 'good' condition while the stream-side zone sub-index rated as 'poor'. The 'riparian width', 'structural intactness', 'longitudinal continuity' and 'overstorey regeneration' indicators all suggested major or extreme modification from natural conditions. Management problems for this tributary include the presence of weed species such as blackberries, thistle and ragwort, limited to no riparian zone, erosion and stock access to the riverbanks.
Hydrological connectivity for the tributary was assessed as being 'near ideal' due to the fact that only one bridge was investigated. However there are a succession of on-stream dams located along the tributary and these were noted to cause siltation and flow problems at the site that was assessed for river condition. The presence of these dams and an absence of appropriate fish ladders to allow unimpeded movement of fish have meant that this tributary has become hydrologically isolated from the rest of the catchment. This tributary is situated in the upper reaches of the Duck River catchment, therefore the impact on a whole of catchment level is still relatively small.

6. Conclusions and Recommendations

The Index of River Condition quantifies the deviation of a reach away from a natural condition both in terms of physical form and the condition of the stream-side zone. The technique also identifies potential degradation issues for each reach within the Duck River catchment which are currently, or have the potential to reduce riverine quality. Using the ratings generated from this study it is possible to target areas for river rehabilitation activities aimed at improving the overall condition of impacted areas. These may include:

- Better stream-side zone management to allow the re-establishment of an appropriate buffer strip of native species.
- Weed reduction and long term control programs.
- Stream bank protection by limiting stock access and control of stream bank erosion.

The hydrological connectivity component of the study has identified in-stream structures that act as barriers to fish migration. The interpretation of ratings has identified areas in the catchment that restrict fish passage at present and should provide a basis for the planning of future in-stream storage development for the catchment. Future development should aim to protect tributaries that have unrestricted fish passage.

The IRC has provided a baseline of information that can be used for comparative purposes to observe changes within the catchment over time. With a management plan in place for the catchment, it would be possible to repeat the IRC survey in 5 years using the same sites to determine if the overall physical condition of the catchment has improved or declined.

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8. APPENDICES

APPENDIX 1: Duck River sites list with grid references, altitude and catchment area above the site for each study location.

Site No.	Site Name	Easting	Northing	Altitude (m)	Catchment Area (Km^2)
DUCK01	Duck R @ Bass H'way	339800	5475500	10	363.7
DUCK02	Duck R @ Kubanks Rd	340700	5475000	10	359.2
DUCK03	Duck R @ Trowutta Rd u/s Geales Ck	340900	5472400	10	306.2
DUCK04	Duck R @ Lades Rd	339950	5469700	10	294.4
DUCK05	Duck R @ Huetts Rd	337200	5464100	15	159.1
DUCK06	Duck R @ Poilinna Rd	335200	5461700	30	104.3
DUCK07	Duck R off Brodies Rd	335800	5459300	30	54.2
DUCK08	Duck R @ Trowutta Rd	337300	5458600	38	51.9
DUCK09	Duck R @ Maguires Rd	342000	5457900	75	27
DUCK10	Duck R @ Wedge Plains Rd	347100	5458100	165	11.2
DUCK11	Coventry Ck above Tall Timbers	341400	5475300	8	19.6
DUCK12	Geales Ck @ Trowutta Rd	340900	5473200	10	26.1
DUCK13	Geales Ck @ Bass H'way	336700	5473100	15	12.8
DUCK14	Geales Ck @ Fagans Rd	333500	5472400	28	8.5
DUCK15	Copper Ck @ Trowutta Rd	340750	5467700	25	10.2
DUCK16	Allen Ck./ Allandale Farm (Blanch Rd)	339450	5466000	15	24.9
DUCK17	Edith Ck @ Huetts Rd	337700	5464700	25	28.6
DUCK18	Edith Ck @ Trowutta Rd @ Edith Creek	339700	5463100	32	22.6
DUCK19	Edith Ck @ quarry off South Rd	340700	5462800	60	18.5
DUCK20	Edith Ck @ quarry off South Rd #2	343700	5461400	115	11.2
DUCK21	Edith Ck @ Lovetts Rd	346500	5461500	215	2.9
DUCK22	Birthday Ck @ Huetts Rd	337700	5463800	20	7.3
DUCK23	Birthday Ck @ Trowutta Rd	338800	5461100	40	1.6
DUCK24	White Water Ck u/s @ Poilinna Rd	336200	5461600	25	4.2
DUCK25	White Water Ck d/s @ Poilinna Rd	336200	5461700	25	4.2
DUCK26	Mill Ck @ Malompto Rd	332200	5461200	45	4.4
DUCK27	Roger R @ Roger River Rd	333050	5455100	35	35.6
DUCK28	Roger R @ Buffs Rd	333200	5452500	50	23
DUCK29	Roger R @ Croles Rd	335900	5451600	110	13.1
DUCK30	Spinks Ck @ Roger River Rd	333900	5455600	35	10.7
DUCK31	Spinks Ck off Bills Rd	334800	5455100	50	8.7
DUCK32	Spinks Ck @ Croles Rd	337900	5453800	165	3.1
DUCK33	Faheys Ck @ Maguires Rd near Jones Rd	340900	5457800	98	4.3
DUCK34	Lairds Ck @ Maguires Rd	342750	5458800	95	5.4

Appendix 2: Dam location details for the Duck Catchment as at October 2002.

DAM ID	EASTING	NORTHING	CAPACITY ML	STREAM NAME	DAM ID	EASTING	NORTHING	CAPACITY ML	STREAM NAME
2148	346000	5466700	20	Allen Creek	2111	341600	5473400	0.1	Bellingers Creek
6548	346100	5465700	75	Allen Creek	2131	339200	5460300	12	Birthday Creek
6549	346300	5464900	50	Allen Creek	2137	345500	5464900	4	Blizzards Creek
2132	346200	5466900	5.3	Allen Creek trib	2156	345100	5464300	23	Blizzards Creek
2133	345900	5466800	5	Allen Creek trib	2159	345300	5464200	41.6	Blizzards Creek
2134	346300	5466700	5.3	Allen Creek trib	5663	346700	5463800	70	Blizzards Creek
2138	345900	5466200	5	Allen Creek trib	7045	347227	5462959	30	Blizzards Creek
2139	345200	5466600	4	Allen Creek trib	2135	344800	5466800	14	Blizzards Creek trib
2140	345200	5466700	3.5	Allen Creek trib	2136	344900	5466800	37	Blizzards Creek trib
2141	344800	5466700	9	Allen Creek trib	2150	345700	5464800	3	Blizzards Creek trib
2142	346200	5465200	9	Allen Creek trib	2151	345500	5464900	4	Blizzards Creek trib
2143	346300	5464700	2	Allen Creek trib	5124	345200	5463900	2.5	Blizzards Creek trib
2144	346200	5465100	10	Allen Creek trib	7109	347200	5464100	90	Blizzards Creek trib
2145	346300	5465500	12	Allen Creek trib	6863	338700	5464500	250	Catchment
2146	345800	5465500	10	Allen Creek trib	4606	342100	5466300	170	Copper Creek trib
2147	345700	5466700	2	Allen Creek trib	4607	343400	5466400	2	Copper Creek trib
2149	346300	5465300	1	Allen Creek trib	4884	341900	5466200	3.3	Copper Creek trib
2152	343000	5464000	20	Allen Creek trib	4907	344700	5467700	124	Copper Creek trib
2153	342800	5463500	4.5	Allen Creek trib	5589	343400	5466800	12	Copper Creek trib
2155	340400	5465200	12	Allen Creek trib	5883	343100	5469700	48	Copper Creek trib
2157	344500	5464100	40	Allen Creek trib	5884	343200	5469900	10	Copper Creek trib
2158	344400	5464200	20	Allen Creek trib	6194	344000	5466900	8	Copper Creek trib
4426	344100	5464500	7	Allen Creek trib	7088	342500	5469400	160	Copper Creek trib
4696	346300	5466900	4	Allen Creek trib	4849	335100	5453400	7.5	Coronation Creek
4697	346400	5466700	4	Allen Creek trib	5052	335100	5453900	50	Coronation Creek
5927	344500	5466200	5	Allen Creek trib	2112	342600	5473400	41	Coventry Creek
6085	340900	5465400	10	Allen Creek trib	2087	342000	5474300	36	Coventry Creek trib
6086	341200	5465600	25	Allen Creek trib	2088	342200	5474300	4	Coventry Creek trib
2109	342500	5473400	2.2	Bellingers Creek	4753	341400	5474900	13	Coventry Creek trib
2110	342500	5473500	2.2	Bellingers Creek	5791	343300	5473300	24	Drain

DAM ID	EASTING	NORTHING	CAPACITY ML	STREAM NAME	DAM ID	EASTING	NORTHING	CAPACITY ML	STREAM NAME
4151	339600	5463200	10.6	Drive Creek	2170	344200	5461700	1	Edith Creek trib
6467	340300	5461500	2	Drive Creek trib	2171	345100	5461500	1.4	Edith Creek trib
2108	341300	5470600	54	Duck River trib	2172	343300	5461700	11	Edith Creek trib
2113	342400	5472000	4.5	Duck River trib	2174	343400	5461500	2	Edith Creek trib
2114	342800	5472000	9	Duck River trib	2177	341900	5462100	7.3	Edith Creek trib
2117	340100	5457500	67	Duck River trib	2178	340900	5462200	16	Edith Creek trib
2160	340900	5468000	20	Duck River trib	2179	341200	5462200	16	Edith Creek trib
3824	341200	5469800	9.6	Duck River trib	2180	341100	5462100	16	Edith Creek trib
3825	341200	5469800	13	Duck River trib	2181	341500	5462200	25	Edith Creek trib
3908	341000	5469300	75	Duck River trib	2296	347100	5461100	12	Edith Creek trib
4123	338000	5477000	0.75	Duck River trib	3999	346900	5462100	13	Edith Creek trib
4295	341800	5470800	20	Duck River trib	4000	346700	5462000	10.5	Edith Creek trib
4296	341600	5470800	10.5	Duck River trib	4001	347100	5462500	10.5	Edith Creek trib
4314	342700	5465500	27	Duck River trib	4068	345800	5462500	8.5	Edith Creek trib
5217	341700	5468700	11	Duck River trib	4150	339600	5462900	4.5	Edith Creek trib
5218	341600	5468700	14	Duck River trib	4254	346800	5461200	14.5	Edith Creek trib
5311	339700	5476100	2.37	Duck River trib	5019	340400	5464200	5	Edith Creek trib
5312	339500	5476800	3.9	Duck River trib	5020	340300	5464100	36	Edith Creek trib
5313	340200	5477000	6	Duck River trib	5325	342300	5462500	43	Edith Creek trib
5370	340700	5468700	1	Duck River trib	6196	346300	5463300	60	Edith Creek trib
5400	341200	5468500	4	Duck River trib	5768	339600	5456600	14	Faheys Creek
5401	341300	5468500	3	Duck River trib	6735	339100	5455200	5	Faheys Creek trib
6017	338500	5476300	12	Duck River trib	2105	331700	5470400	7	Geales Creek
6419	341500	5472100	3	Duck River trib	3935	331900	5471800	14	Geales Creek
6420	341600	5471600	14	Duck River trib	3936	331800	5472400	2.5	Geales Creek
6536	341500	5470300	90	Duck River trib	4531	339300	5472700	0.25	Geales Creek
6676	340800	5468300	60	Duck River trib	5461	332000	5470700	2	Geales Creek
6851	341100	5468500	5	Duck River trib	2089	333000	5469900	4	Geales Creek trib
6852	341400	5468600	7	Duck River trib	2103	332000	5471600	75	Geales Creek trib
6917	338900	5468500	60	Duck River trib	2104	331400	5470600	8	Geales Creek trib
2168	344400	5461400	90	Edith Creek	3009	333200	5471000	4	Geales Creek trib
2175	347000	5462500	37	Edith Creek	2119	336500	5455800	3.3	Greenes Creek
2176	346600	5461600	37	Edith Creek	6219	335200	5456500	1	Greenes Creek trib
6981	341900	5460900	110	Edith Creek	5468	341300	5454800	1	Harry Ryan Creek
6982	341900	5460900	90	Edith Creek	2107	341600	5454400	9	Harry Ryan Creek trib
2167	344200	5461700	27.6	Edith Creek trib	3336	341400	5453900	3	Harry Ryan Creek trib
2169	344400	5460900	5.5	Edith Creek trib	3337	341400	5454100	3.3	Harry Ryan Creek trib

DAM ID	EASTING	NORTHING	CAPACITY ML	STREAM NAME	DAM ID	EASTING	NORTHING	CAPACITY ML	STREAM NAME
2090	341300	5455000	5	Joiner Creek	4850	334200	5453200	3.5	Roger River trib
2091	341200	5455000	51.7	Joiner Creek	4851	334300	5453200	17	Roger River trib
2092	341300	5455400	2.4	Joiner Creek trib	4852	335100	5452800	2	Roger River trib
2093	341300	5455600	23.3	Joiner Creek trib	5922	334900	5455400	10	Roger River trib
2094	341300	5455700	39.6	Joiner Creek trib	2191	339000	5453600	8	Spinks Creek
2102	341200	5456200	26	Joiner Creek trib	3340	339800	5454500	10	Spinks Creek
2095	343800	5459100	7	Lairds Creek	3341	339500	5454300	6	Spinks Creek
2096	343600	5459100	4	Lairds Creek	4846	338100	5453800	23	Spinks Creek
2097	343500	5459100	5	Lairds Creek	6335	338500	5453800	20	Spinks Creek
2098	343200	5459100	10.5	Lairds Creek	6446	334500	5455200	5.2	Spinks Creek
2099	343000	5459000	6	Lairds Creek	4845	338300	5453500	28	Spinks Creek trib
2124	344600	5459500	5.3	Lairds Creek	5053	336300	5454300	11.5	Spinks Creek trib
2125	345000	5460000	2.98	Lairds Creek	6336	338800	5453400	5	Spinks Creek trib
2126	345000	5460000	18	Lairds Creek	4682	343900	5471600	155	U/N Drain into Coventry Ck
2127	344300	5459200	5	Lairds Creek	2154	347300	5465500	9.6	Vales Creek
2128	345600	5460100	35	Lairds Creek	6306	344500	5467700	2	Vales Creek
2129	345200	5460100	45	Lairds Creek	6410	346900	5465800	3	Vales Creek
2130	345100	5459800	117	Lairds Creek	4587	339000	5457800	60	Whelans Creek trib
5664	343600	5459100	30	Lairds Creek	4588	339300	5457900	14	Whelans Creek trib
2100	342500	5459000	18.5	Lairds Creek trib	5442	338400	5458300	6	Whelans Creek trib
4255	346500	5460400	3	Maguires Creek	5788	338300	5457300	23	Whelans Creek trib
4256	346300	5460700	2.3	Maguires Creek	2121	337200	5456400	10	Williamsons Creek
4257	346700	5460300	8	Maguires Creek	4253	335700	5457200	1.25	Williamsons Creek
2118	336200	5455200	5.5	McDonald Creek trib	5240	337700	5455900	1.6	Williamsons Creek
2120	337500	5455300	6.5	McDonald Creek trib	5241	337800	5455800	4.8	Williamsons Creek
2122	337300	5455400	2	McDonald Creek trib	5242	337900	5455600	5.5	Williamsons Creek
2123	337200	5455400	2.4	McDonald Creek trib	5243	338000	5455600	0.75	Williamsons Creek
6117	339200	5461500	3	Pykes Creek	5244	337700	5455700	4.5	Williamsons Creek
4242	339500	5450300	370	Roger River	5245	337800	5455600	1	Williamsons Creek
4456	336600	5452400	10	Roger River trib					
4848	335100	5452900	15	Roger River trib					

Appendix 3: IRC Sub-index ratings and indicator values for the Duck River catchment sites.

		Physical form						Stream-side zone							
Site	Morphology	Physical form rating	Bank	Bed	Barrier	CWD	OSD	Stream-side rating	Riparian width	Struct. intact.	% indig.	Regen.	LC	Overst regen.	SC
DUCK01 Duck R @ Bass H'way	floodplain	6.67						1.63							
DUCK02 Duck R @ Kubanks Rd	floodplain	6.90						2.24							
DUCK03 Duck R @ Trowutta Rd u/s Geales Ck	floodplain	4.76						1.54							
DUCK04 Duck R @ Lades Rd	floodplain	5.71						3.80							
DUCK05 Duck R @ Huetts Rd	floodplain	5.95						3.43							
DUCK06 Duck R @ Poilinna Rd	floodplain	7.62						1.59							
DUCK07 Duck R off Brodies Rd	floodplain	7.38						1.63							
DUCK08 Duck R @ Trowutta Rd	floodplain	8.33						4.15							
DUCK09 Duck R @ Maguires Rd	valley	8.82						7.34							
DUCK10 Duck R @ Wedge Plains Rd	floodplain	9.76						8.59							
DUCK11 Coventry Ck above Tall Timbers	floodplain	5.00						1.68							
DUCK12 Geales Ck @ Trowutta Rd	floodplain	5.71						2.07							
DUCK13 Geales Ck @ Bass H'way	floodplain	3.10						0.38							
DUCK14 Geales Ck @ Fagans Rd	floodplain	7.38						4.26							
DUCK15 Copper Ck @ Trowutta Rd	floodplain	6.67						2.84							
DUCK16 Allen Ck./ Allandale Farm (Blanch Rd)	floodplain	6.19						0.38							
DUCK17 Edith Ck @ Huetts Rd	floodplain	4.05						0.38							
DUCK18 Edith Ck @ Trowutta Rd @ Edith Creek	floodplain	5.24						0.38							
DUCK19 Edith Ck @ quarry off South Rd	floodplain	10.00						7.56							
DUCK20 Edith Ck @ quarry off South Rd #2	floodplain	4.29						2.16							
DUCK21 Edith Ck @ Lovetts Rd	floodplain	7.14						4.79							
DUCK22 Birthday Ck @ Huetts Rd	floodplain	3.81						0.38							
DUCK23 Birthday Ck @ Trowutta Rd	floodplain	9.05						4.46							
DUCK24 White Water Ck u/s @ Poilinna Rd	floodplain	5.71						8.65							
		Physical form						Stream-side zone							

Site	Morphology	Physical form rating	Bank	Bed	Barrier	CWD	OSD	Stream-side rating	Riparian width	Struct. intact.	% indig.	Regen.	LC	Overst regen.	SC
DUCK25 White Water Ck d/s @ Poilinna Rd	floodplain	4.05						0.38							
DUCK26 Mill Ck @ Malompto Rd	valley	8.82						10.00							
DUCK27 Roger R @ Roger River Rd	floodplain	5.71						1.30							
DUCK28 Roger R @ Buffs Rd	valley	10.00						8.29							
DUCK29 Roger R @ Croles Rd	valley	10.00						8.85							
DUCK30 Spinks Ck @ Roger River Rd	floodplain	6.43						1.92							
DUCK31 Spinks Ck off Bills Rd	valley	8.82						8.94							
DUCK32 Spinks Ck @ Croles Rd	floodplain	6.19						0.38							
DUCK33 Faheys Ck @ Maguires Rd near Jones Rd	valley	6.47						1.99							
DUCK34 Lairds Ck @ Maguires Rd	floodplain	7.38						2.80							

	Indicator suggests major or extreme difference from natural or ideal conditions
	Inadequate data to evaluate sub-index.
	Adequate data to evaluate indicator and ratings suggest changes have not been extreme or major.

CWD = Coarse woody debris
OSD = Overall site disturbance.
LC = Longitudinal continuity
SC = Stream-side cover.
Regen = Regeneration of indigenous species.

Appendix 4. Artificial barriers - locations, type and rating for the Duck River

No.	Barrier Name	Easting	Northing	Type	Value (0-10)	Rating (0-5)
1	Duck R @ Bass Highway (DUCK01)	339800	5475500	Bridge	7.14	3
2	Duck R @ Trowutta Rd (Smithton)	341290	5474170	Bridge	7.50	3
3	Duck R @ Trowutta Rd (DUCK03)	340920	5472520	Bridge	7.50	3
4	Duck R @ Lades Rd (DUCK04)	339950	5469700	Bridge	7.86	3
5	Duck R @ Huetts Rd (DUCK05)	337200	5464100	Bridge	7.86	3
6	Duck R @ Poilinna Rd (DUCK06)	335200	5461700	Bridge	7.86	3
7	Duck R @ Trowutta Rd	341410	5473720	Weir	7.14	3
8	Duck R @ Trowutta Rd (Roger River) (DUCK08)	337300	5458600	Bridge	8.93	4
9	Duck R @ Maguires Rd (DUCK09)	342000	5457900	Bridge	8.21	4
10	Duck R @ Wedge Plains Rd (DUCK10)	347100	5458100	Bridge	9.64	4
11	Un-named trib, lower catchment @ Mella Rd	337200	5476300	Culvert	4.64	2
12	Un-named trib, lower catchment @ Mella Rd	337100	5476200	Culvert	4.64	2
13	Coventry Ck @ Trowutta Rd (Smithton)	341200	5475200	Bridge	6.79	3
14	Coventry Ck @ Connel Cross Rd	342800	5471800	Culvert	4.64	2
15	Geales Ck @ Trowutta Rd (DUCK12)	340900	5473200	Bridge	7.14	3
16	Geales Ck @ Bass Highway (DUCK13)	336700	5473100	Culvert	5.71	2
17	Geales Ck @ Fagans Rd (DUCK14)	333500	5472400	Bridge	7.14	3
18	Geales Ck @ Fagans Rd	333500	5472300	Culvert	5.71	2
19	Geales Ck off Fagans Rd	333500	5472330	Culvert	6.43	3
20	Plains Ck @ Goldings Rd	337700	5468360	Culvert	7.14	3
21	Copper Ck @ Trowutta Rd (DUCK15)	340750	5467700	Bridge	6.79	3
22	Allen Ck @ Trowutta Rd	340090	5465030	Bridge	6.79	3
23	Allen Ck @ South Rd	345600	5467100	Bridge	7.50	3
24	Allen Ck @ Youngs Rd	344050	5466700	Bridge	7.50	3
25	Blizzards Ck @ Youngs Rd	344000	5466700	Bridge	7.14	3
26	Blizzards Ck @ South Rd	345400	5464100	Dam	2.14	1
27	Blizzards Ck @ South Rd	345300	5464100	Culvert	4.29	2
28	Un-named trib @ Lades Rd	339500	5470000	Bridge	7.50	3
29	Edith Ck @ Huetts Rd (DUCK17)	337700	5464700	Bridge	6.43	3
30	Edith Ck @ Trowutta Rd (DUCK18)	339700	5463100	Bridge	7.14	3
31	Edith Ck @ Lovetts Rd (DUCK21)	346600	5461500	Culvert	4.64	2
32	Edith Ck @ Lovetts Rd	346600	5461500	Dam	1.43	0
33	Birthday Ck @ Huetts Rd (DUCK22)	337700	5463800	Culvert	7.14	3
34	Birthday Ck @ Poilinna Rd	338200	5462200	Culvert	6.43	3
35	Birthday Ck @ Trowutta Rd (DUCK23)	338800	5461100	Culvert	6.43	3
36	White Water Ck @ Poilinna Rd (DUCK24)	336200	5461600	Bridge	8.21	4
37	Mill Ck @ Malompto Rd (DUCK26)	332260	5461090	Culvert	8.57	4
38	Roger R @ Roger River Rd (DUCK27)	333050	5455100	Bridge	8.21	4
39	Roger R @ Croles Rd (DUCK29)	335900	5451600	Bridge	8.93	4
40	Spinks Ck @ Roger River Rd (DUCK30)	333900	5455600	Bridge	7.14	3
41	Spinks Ck @ Croles Rd (DUCK32)	337900	5453800	Bridge	8.21	4
42	Greenes Ck @ Roger River Rd	335520	5456830	Culvert	5.71	2
43	Williamsons Ck @ Roger River Rd	335830	5457050	Culvert	6.43	3
44	Faheys Ck @ Maguires Rd	339800	5457150	Culvert	2.86	1
45	Faheys Ck @ Maguires Rd	340000	5457200	Dam	2.86	1
46	Lairds Ck @ Maguires Rd (DUCK34)	342750	5458800	Bridge	7.86	3

Appendix 5: Overall site disturbance indicator categories for the physical form sub-index

1. EXTREME DISTURBANCE	
Riparian vegetation	**Absent or severely reduced. Vegetation present is severely disturbed - i.e. dominated by exotic species. Native species are rare or absent.**
Surrounding vegetation	**Agriculture and/or cleared BOTH sides. Plants present are virtually all exotic species (pines, willows, etc.)**
2. VERY HIGH DISTURBANCE	
Riparian vegetation	**Some native vegetation present, but it is severely modified BOTH sides by grazing or the intrusion of introduced species. Native species severely reduced in numbers (species richness) and cover.**
Surrounding vegetation	**Agriculture and/or cleared BOTH sides. Plants present are virtually all exotic species (pines, willows, etc.).**
3. HIGH DISTURBANCE	
Riparian vegetation	**Moderately disturbed by stock or through the intrusion of introduced species, though native species remain in reasonable numbers and abundance.**
Surrounding vegetation	**Agricultural land and/or cleared on ONE side; native vegetation on the other clearly disturbed or with a high percentage of introduced species.**
4. MODERATE DISTURBANCE	
Riparian vegetation	**Native vegetation on BOTH sides with canopy intact or with native species widespread and common. The intrusion of introduced species is minor and of moderate impact.**
Surrounding vegetation	**Agricultural land and/or cleared on ONE side; native vegetation on the other in a relatively undisturbed state.**
5. LOW DISTURBANCE	
Riparian vegetation	**Native vegetation on BOTH sides of the river in generally good condition with few introduced species present. Any disturbance is minor.**
Surrounding vegetation	**Native vegetation present on BOTH sides of the river with a virtually intact canopy. Minor disturbance present through introduced species.**
6. VERY LOW DISTURBANCE	
Riparian vegetation	**Native vegetation on both sides of the river in an undisturbed state. Introduced species are rare or insignificant. Representative of pristine condition.**
Surrounding vegetation	**Native vegetation on both sides of the river with an intact canopy. Introduced species are rare or insignificant. Representative of pristine condition.**

Appendix 6: Management issues identified for the Duck River main stream and tributary sites.

Reach	Management Issues
(DUCK01) Duck R @ Bass Highway	Weeds - Willows, blackberries (*Rubus fruticosus*). Limited riparian zone dominated by willows. Unrestricted stock access to river banks. Silt build-up in-stream
(DUCK02) Duck R @ Kubanks Rd	Weeds - Willows, blackberries and thistles. Limited riparian zone dominated by willows. Stock access to river banks unrestricted apart from small section. Limited indigenous plant regeneration.
(DUCK03) Duck R @ Trowutta Rd u/s Geales Ck	Weeds – Willows and Blackberries. Limited riparian zone dominated by willows. Unrestricted stock access to river banks. Unstable banks and excessive siltation in-stream. Limited indigenous plant regeneration
(DUCK04) Duck R @ Lades Rd	Weeds - blackberries. Riparian zone absent in sections, moderate indigenous vegetation cover , unrestricted stock access and heavy in-stream siltation
(DUCK05) Duck R @ Huetts Rd	Weeds – Bullrushes, thistles, blackberries. Limited riparian zone. Unrestricted stock access to river banks, considerable stock damage to river banks, excessive in-stream siltation and rubbish dumped in river.
(DUCK06) Duck R @ Poilinna Rd	Weeds - Blackberries, thistles (extensive). Limited indigenous plant regeneration. Unrestricted stock access to river banks.
(DUCK07) Duck R off Brodies Rd	Weeds - Willows. Unlimited stock access to river banks. Little to no riparian zone on left bank and indigenous plant regeneration present
(DUCK08) Duck R @ Trowutta Rd (Roger River)	Weeds - Blackberries. Limited riparian cover for right bank and some unrestricted stock access.
(DUCK09) Duck R @ Maguires Rd	Small section of absent riparian zone on right bank.
(DUCK10) Duck R @ Wedge Plains Rd	No issues
(DUCK11) Coventry Ck above Tall Timbers	Weeds - Blackberry, willow, thistles (extensive). Limited to no riparian zone. Sparse indigenous plant regeneration. Unrestricted stock access to river banks, considerable stock damage to river banks, excessive instream siltation and algal cover.
(DUCK12) Geales Ck @ Trowutta Rd	Weeds - Blackberries, thistles. Limited riparian zone and channelisation present.
(DUCK13) Geales Ck @ Bass H'way	Weeds - Blackberry. No riparian zone and no indigenous plant regeneration. Unrestricted stock access to both banks. Extensive bank erosion and heavy siltation.
(DUCK14) Geales Ck @ Fagans Rd	Weeds – Blackberries (extensive). Stock damage to banks in upstream section, heavy siltation..
(DUCK15) Copper Ck @ Trowutta Rd	Weeds – Willow (sparse), blackberries, thistles, ragwort. Sparse riparian zone and limited indigenous plant regeneration.
(DUCK16) Allen Ck./ Allandale Farm (Blanch Rd)	No riparian zone present and no regeneration of indigenous plant species. Unrestricted stock access to river banks, considerable stock damage to river banks, excessive in-stream siltation and rubbish dumped in river.
(DUCK17) Edith Ck @ Huetts Rd	Weeds - Blackberry. No riparian zone and no indigenous plant regeneration. Partial stock access to river banks. Stock damage to banks evident.
(DUCK18) Edith Ck @ Trowutta Rd	Weeds - Blackberry. No riparian zone and no indigenous plant

@ Edith Creek	regeneration. Partial stock access to river banks. Stock damage to banks evident.
(DUCK19) Edith Ck @ quarry off South Rd	Native forest. Rubbish from road needs removal from stream.
(DUCK20) Edith Ck @ quarry off South Rd #2	Weeds - Willows (extensive), blackberry, thistles. Stock accessing creek, damage to banks evident, riparian zone lacking in parts.
(DUCK21) Edith Ck @ Lovetts Rd	Weeds – Blackberry. Part of riparian zone is cleared. Unrestricted stock access on left bank and excessive silt and algae in-stream.
(DUCK22) Birthday Ck @ Huetts Rd	No riparian zone. Stock access unrestricted on left bank and associated erosion of banks is evident. Creek has been channelised.
(DUCK23) Birthday Ck @ Trowutta Rd	Weeds – Thistles. Riparian zone lacking in sections. Excessive rubbish in creek.
(DUCK24) White Water Ck u/s @ Poilinna Rd	Weeds – Blackberries, pines. Erosion problems associated with channelisation of the creek.
(DUCK25) White Water Ck d/s @ Poilinna Rd	Weeds - Thistles. No riparian zone. Bank erosion, unrestricted stock access, channelisation and choked with aquatic weeds.
(DUCK26) Mill Ck @ Malompto Rd	No specific issues apart from excessive silt levels in-stream.
(DUCK27) Roger R @ Roger River Rd	Weeds – Willows, blackberries, thistles. Stock access to each bank along sections of the reach. Moderate erosion. Limited riparian zone.
(DUCK28) Roger R @ Buffs Rd	No specific issues
(DUCK29) Roger R @ Croles Rd	No specific issues
(DUCK30) Spinks Ck @ Roger River Rd	Weeds – Willow (excessive), thistles, blackberries. Limited riparian zone, with poor indigenous plant regeneration. Unrestricted stock access to banks.
(DUCK31) Spinks Ck off Bills Rd	No specific issues
(DUCK32) Spinks Ck @ Croles Rd	Weeds – Blackberries, thistle, ragwort. Sparse riparian zone through reach and pine plantation upstream. Unrestricted stock access to banks.
(DUCK33) Faheys Ck @ Maguires Rd near Jones Rd	Weeds – Blackberry. Poor riparian zone. Spot erosion. Unrestricted stock access.
(DUCK34) Lairds Ck @ Maguires Rd	Weeds – Blackberry (excessive), thistle, ragwort. Limited riparian zone. Spot erosion. Stock access to parts of both banks. Siltation and flow problems from upstream dam.