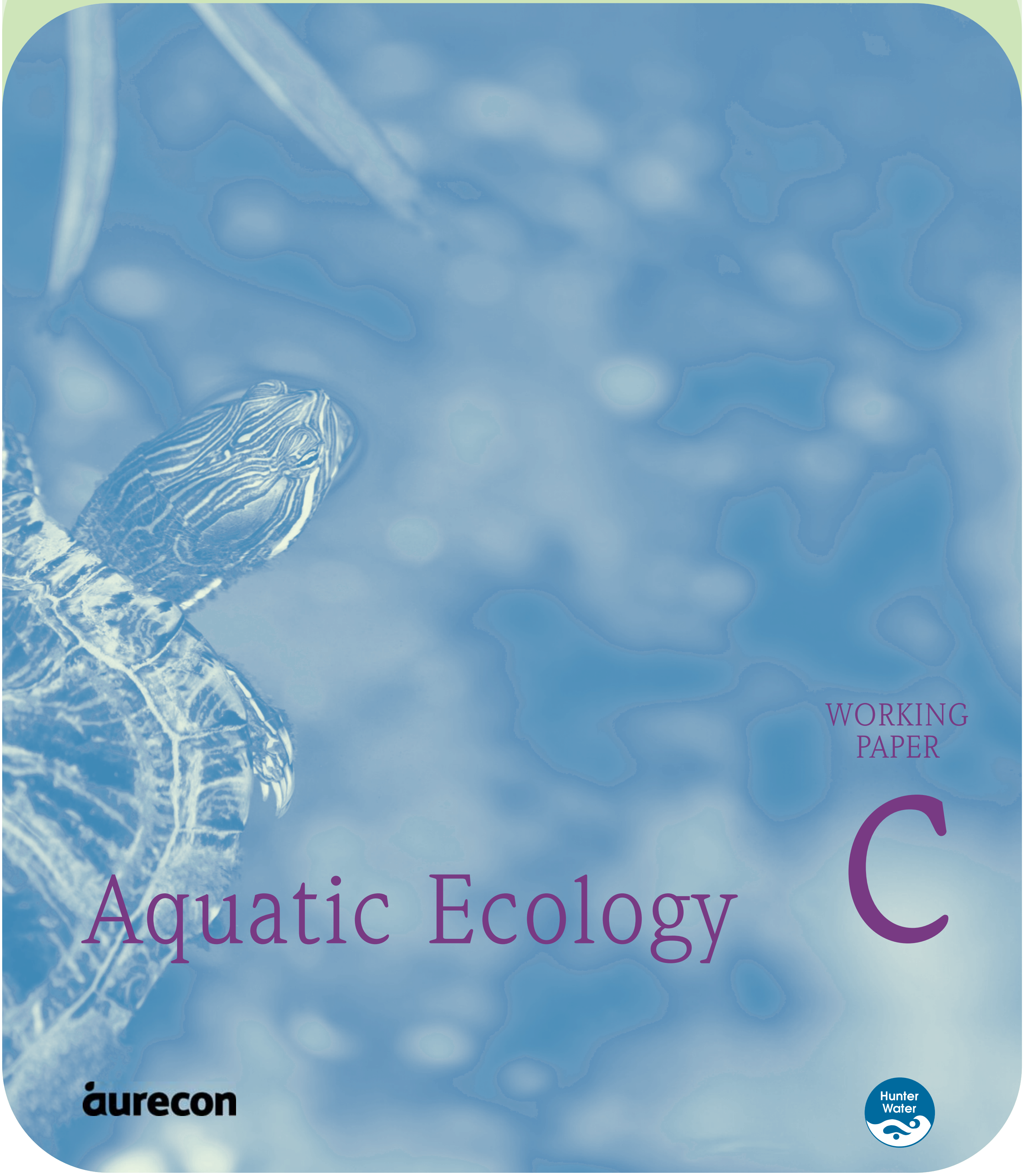
Tillegra Dam

Planning and Environmental Assessment



WORKING PAPER

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Aquatic Ecology

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Hunter Water

Report to:

Connell Wagner PPI

Aquatic Ecology Assessment

For the Construction and Operation of Tillegra Dam

FINAL

August 2008

The Ecology Lab Pty Ltd

Marine and Freshwater Studies

Aquatic Ecology Assessment

For the Construction and Operation of Tillegra Dam

August 2008

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TABLE OF CONTENTS

SUMMARY

Connell Wagner, on behalf of Hunter Water, has commissioned The Ecology Lab to conduct an aquatic ecological assessment in relation to the proposed construction and operation of the Tillegra Dam on the Williams River.

The construction and operation of dams can cause a variety of impacts to river ecosystems. The proposed construction of Tillegra Dam would alter approximately 19 km of existing lotic (running water) habitats in the upper Williams River, transforming them to a much larger, contiguous lentic (standing water) habitat. The project may alter lotic habitats downstream of the dam such as riffles and pools by scouring the channel bed, changing the natural flow regime and creating a barrier to aquatic organisms moving up and/or down the Williams River.

The aim of the aquatic assessment was to examine the potential effects of dam construction and operation on aquatic habitats and communities in the Williams River, above, within and below the proposed inundation area. The aims included:

- assessment of ecological status of the Williams River;
- identification of threatened and protected fish and aquatic macroinvertebrate species, populations and communities that may be present in the Williams River;
- identification of pest species in the Williams River;
- assessment of aquatic habitat and communities in reaches of the river to be inundated, in reaches upstream and downstream of the proposed impoundment;
- predictions of impacts on dam construction and operation on ecology of aquatic habitats and communities;
- recommendations for environmental flows required to maintain ecological structure and function of the Williams River.

The Williams River catchment has experienced considerable historical land clearing for agriculture. The river channel has been extensively modified as a result of flood mitigations works, such as channel straightening, drainage works, the removal of instream woody debris and aquatic vegetation. Flows have been regulated by the construction of the Chichester Dam, the Seaham Weir, various grading devices and extraction by irrigators. Water quality is relatively good although there is a gradient of nutrient enrichment that increases downstream, associated with nutrient inputs from the surrounding agricultural land use. This has led to blue-green algal blooms in lentic sections of the river, particularly the Seaham Weir pool.

Previous studies have found that aquatic macroinvertebrate communities in riffle and edge habitat from below Salisbury to Mill Dam Falls were in good condition, biodiverse and had sensitive species well represented. Sixteen species of fish have been recorded within the Williams River above Seaham Weir, including the introduced mosquitofish. Twelve species have been identified above the proposed dam wall site, eight of which are putatively diadromous and must spend part of there lifecycle downstream of the dam in estuarine waters. No fish or invertebrate species recorded in the Williams River are listed as threatened or protected but there are four listed key threatening processes relevant to the proposal. The most significant threatening process relates to the installation of instream

structures and how the dam may affect populations of migrating fish, resulting in population fragmentation, decline or even depletion above the barrier.

Twelve sites were selected to be surveyed along the Williams River; ten sites were sampled in November and December 2007 and the two most downstream sites could not be sampled due to high flows following heavy rainfall. The survey included two sites in the reach above the full storage level of the proposed dam reservoir (Reach 1), four sites in the reach to be inundated (Reach 2) and four sites below the proposed dam wall (Reach 3). The latter included two sites upstream of the confluence with the Chichester River and two sites downstream of the Chichester confluence. The field study yielded:

- descriptions of representative habitats surveyed;
- snapshot view at representative locations of key water quality parameters;
- list of aquatic flora, fish and mobile invertebrates caught or observed at each site;
- AusRivAS measure of river health based on the assessment of aquatic macroinvertebrate assemblages in riffle and pool edge habitats.

Total phosphorous and NO_x (nitrate and nitrite) were above the ANZECC critical values for aquatic ecosystem protection at the majority of sites sampled, however Chlorophyll *a* was within ANZECC guidelines at all sites except for the surface waters at Seaham Weir pool. Metal concentrations were generally within the guidelines except for mercury at Seaham Weir pool, and zinc was above the guidelines at all sites. The results for organochlorine pesticides were below the test detection limits at all sites, and for pesticides, however for the limit of detection for some pesticides the tests were not sufficiently low to compare to guideline trigger values.

Combined AusRivAS analysis for both edge and riffle habitat found macroinvertebrate assemblages upstream of the proposed dam (sites W1 – W 6) were comparable to reference conditions but sites downstream of the proposed dam (sites W7 – W10) had significantly fewer taxa than expected, suggesting existing impacts on water quality and/or aquatic habitats. Results from the latter sites should be interpreted with caution as sampling took place during a time of relatively high flows, potentially under representing the number of taxa present, rather than indicating degraded water quality or habitat. Re-sampling of these sites was not possible due to constant high flows within the Williams River.

Over 1,000 fish, representing six species were caught at the ten sites sampled using fish traps, backpack electrofishing and seine nets. The most common species were Australian smelt, Cox's gudgeon and the long-finned eel. These results were similar to other surveys in the area in which fish assemblages were characterised by smelt, Cox's gudgeon, long-finned eel, Australian bass and freshwater catfish. The investigation by The Ecology Lab did not catch any bass or catfish as the higher flows prevented the backpack electrofisher being used effectively in pool habitat where they were more likely to be found.

Assessment of Impacts

Impacts from the dam will occur in a variety of ways. Firstly, construction of the dam and associated earthworks may mobilize sediments into the Williams River, potentially smothering aquatic habitat and impacting on biota. However, these effects can be mitigated with standard sediment control procedures.

Of more significant concern, following the completion of the dam wall, Reach 2 would be inundated, involving the loss of approximately 19 km of main stem lotic habitat at FSL 150 mAHD including riffles, runs and pools and their associated macroinvertebrate fauna. It is likely that some pool edge fauna would persist in the new lentic environment although it would take time to develop microhabitats that would encourage a more lacustrine (lake) fauna to establish. The barrier created by the dam wall to fish passage would likely result in the extirpation of most diadromous fish species above the barrier, throughout Reach 1 and 2, due to recruitment failure because juveniles and adults would be unable to swim downstream to spawn and/or upstream to colonise in the absence of a fish passage structure. This represents 52 km of lost habitat. Exceptions are the long-finned eel, short-finned eel and Cox's gudgeon which are able to climb weirs and dams, although it is expected their abundances would decline. Cox's gudgeon is also thought able to complete its life cycle within freshwater systems. Potamodromous and undefined species would persist in Reach 1, although their populations would become fragmented and they would no longer have access to habitat beneath the dam wall. All these species in Reach 1 have been observed in lentic environments and are expected to inhabit the dam storage. However some species, such as Cox's gudgeon and juvenile long-finned eel have a preference for lotic habitat and may be present in the storage in lower densities than Reach 1.

Other major impacts that will be derived from the dam, relate predominantly to an altered hydrological regime downstream of the storage. Potential impacts are complex and inter-related to the manner in which the existing flow regime is altered by the dam. Potential effects include changes to physical instream habitat, changes to water quality within the reservoir and downstream of the dam, alteration to exogenous cues essential for fish migration, spawning and recruitment as well as other consequential impacts to the overall rivers ecology.

The assessment of potential impacts is therefore reliant on understanding the pre-existing hydrological regime, aquatic habitats and biota with a sub sequential view to estimating how the system may be affected by any departure from this regime. Implicit in this process therefore, is that the future operational aspects of the dam are known.

As a starting point for the assessment of hydrological impacts, a base case scenario for operation of the dam was therefore assumed. It entails constant Run-of-River transfers of water from the Dam to Seaham Weir, of between 250 to 500 ML/day, persisting for up to 30 days at a time. Further, the base case scenario assumes for environmental and third party purposes, transparent releases from the dam to the 90th percentile exceedance on the hydrograph at Tillegra, as well as a translucent release of 60% of water between the 90th and 30th percentile. An intermittent flushing flow of 2000 ML was also considered as part of the base case.

The aquatic environmental assessment required, amongst other matters, consideration of the impacts of the base case flow regime on the aquatic ecology of the Williams River and as part of the process, suggestions of alternate or additional mitigation and management measures that could be adopted by Hunter Water, to improve and refine the release scenario.

The base case scenario is affected by both a filling and operational stage for the dam, which reflects water availability for run of river discharges and environmental releases. During the filling phase overall flows beneath the dam wall in Reaches 3 and 4 would decline as water is diverted to the storage. The ability to predict changes to aquatic biota is hampered by a lack of basic understanding of the flow requirements for many taxa. Diminished flows may lead to lower water quality, a reduction in the availability of aquatic habitat. Lower water quality may result in the impairment of macroinvertebrate assemblages as fewer but more abundant, pollution-tolerant taxa result in communities with lower diversity. The base case release strategy would also tend to favour macroinvertebrates more suited to stable low flow regimes and may select against taxa with high flow needs or life history stages cued to large seasonal changes.

Fish migrating upstream would aggregate at the base of the dam where they are more vulnerable to predation. An increase in the proportion of low to moderate flows may result in changes to the fish assemblages in the reaches below the dam. Fish that can complete their life cycles in freshwater, have preference for lower flows and are tolerant of lower water quality may not be affected. Some taxa, particularly the introduced species, may increase in distribution and abundance. The effect of flow alteration on upstream fish passage is complex and would vary among seasons, species, size classes, barrier type (e.g. between low energy and high energy riffles) and with distance downstream. Small migrating fish may experience a possible increase in passage in Reach 3 although gains may be limited by minimal change at the downstream, high energy Mill Dam Falls riffle at Glen Martin. The opposite would be true for larger fish. At Seaham Weir, a decline in high flows would reduce opportunities for large fish to negotiate passage during weir 'drown out' or through the open weir gates during periods of low head differential. Conversely, more low flows may increase the frequency of low to negative head differential events (between the weir pool and the tidal tailwater) that inadvertently facilitate passage of diadromous juvenile fish through the otherwise ineffective submerged orifice fishway. Changes in passage at Seaham Weir, and to a lesser extent Mill Dam Falls, can have important consequences for upstream recruitment as these two sites govern access to 86 km and 63 km of main stem habitat respectively (and further if a fish lift is built at Tillegra Dam).

The significant loss of a range of larger peak flows would lead to a decline in successful spawning and/or recruitment for some diadromous species. The downstream migration of these fish is cued or facilitated by elevated seasonal flows. Recruitment and recreational catch of Australian bass is proportional to flow and peak events during the spawning year. Certain impacts within Reaches 3 and 4 are expected to compound and increase with time as the dam fills.

The operational phase of Tillegra Dam would retain large flows, although the subsequent release of Run-of-River transfers and spilling flows would result in an increase in flows of 250 – 500 ML/day at the expense of low to moderate (and large) flows. Protocols for releasing water can be initiated by Hunter Water to accommodate seasonality. Care should therefore be taken to ensure that they have the same temporal distribution as historical flows of this magnitude, and not result in median flow increases during spring (a season historically dominated by periods of stable low flow) and to a lesser extent summer. The initiation of Run-of-River transfers and spilling flows should improve water and habitat quality that may have become degraded during the filling phase, and therefore the recovery of sensitive macroinvertebrate taxa. A rise in channel 'wetted width' would increase the overall productivity of riffle communities and habitat availability for associated fish species. As sediments are trapped behind the dam, scouring flows that mobilize bed materials would remove riffles and expose bedrock in sections of the Williams River downstream of the dam wall. Macroinvertebrate assemblages and fish associated with this habitat would be greatly impaired or lost.

The base case scenario stipulated that once Grahamstown Dam reached a predefined level, Run-of-River flows would be initiated. An analysis of when this would occur suggested that drawdown at Grahamstown and hence, initiation of Run-of-River transfers, was most likely during spring and summer. If protocols for flows were not adopted to take into account seasonality increased flows during spring may decrease local recruitment for those macroinvertebrate and fish taxa that have life histories adapted to a period historically characterised by stable low flows. Such an operational regime may also reduce the proportion of diadromous fish recruiting upstream into Reach 4 and Reach 3 via passage from estuarine habitat through the Seaham Weir fishway. An increase in median spring and summer flow volume due to the calling of Run-of-River transfers at the wrong time would possibly decrease the amount of time that passage through the fishway is possible during the migration season of diadromous juveniles, because the number of low to negative head differential events would decrease. The proportion of navigable flows within Reach 4 are not anticipated to change as there are few, if any, depth barriers to passage and the low gradient and wide channel results in lower velocity flows. For those fish that do not recruit into Reach 4 but continue upstream, the effects of the operational release regime on fish passage throughout Reach 3 are again relatively complex. Overall, the proportion of upstream navigable flows is predicted to decline to some extent for most fish. Increases in passage over shallow barriers afforded by the extra depth of larger flows are offset by an increase in flows that exceed velocity thresholds.

The volume of seasonal peaks within the operational phase is consistently lower than historical flows and may therefore negatively affect ecological processes that are proportional to flow magnitude, such as bass recruitment.

Recommendations

To reduce some of the predicted environmental impacts derived from the dam, it is recommended that:

- Standard sediment control procedures are used during construction to minimize the mobilization of sediments into the watercourse;
- A lift fishway that has been considered for Tillegra Dam be incorporated into the dam design to connect reaches 1 and 2 with reaches 3 and 4;
- The ineffective submerged orifice fishway at Seaham Weir be replaced with an appropriate design that operates over a wider range of headwater and tailwater levels;
- The base case release strategy should be refined to mimic the historical flow regime, capturing any pattern or seasonality in the frequency, magnitude and duration of flows, as well as the natural variability to which the river flora and fauna are adapted. Releases should be made within the boundaries of natural rates of rise and fall. Proposed changes to the current base case release strategy include:
    - multiple larger peak flow events (e.g. freshes) be released each year during the filling phase and that the timing and relative frequency of these releases should mimic any pattern and seasonality in the historical flow distribution;
    - Run-of-River transfers should commence prior to the dam reaching FSL;
    - That appropriate protocols be established to govern the calling of Run-of-River transfers so that the seasonal flow distribution during dam operation mimics that of the historical period (the base case hydrological data set used in the assessment included a disproportionate allocation of Run-of-River transfers to spring and summer);

  - Should the storage fall below FSL the additional peak event releases are re-initiated until the storage reaches FSL and the potential for spilling resumes;
  - Adequate flows are allocated to the proposed fish lift at Tillegra Dam and upgraded fishway at Seaham Weir;
  - Temporal variability and profile of all environmental flows should occur within the expected limits of equivalent historical flows. For example; the base case Run-of-River transfers detailed a daily transfer volume that is constant for approximately 30 days. The same total volume could be transferred with a more natural profile, such as; shorter event duration, a higher initial peak and a decaying tail;
  - Increase the minimum number of event releases (additional fresh events and Run-of-River transfers) during the filling phase as the time taken to reach FSL increases to reduce possible accumulating impacts of the filling phase release regime;
- That scoured bed material is replenished in the affected section of the Williams River downstream of the dam in Reach 3 providing it can be done so in an environmentally sensitive manner;
- An appropriate monitoring programme is implemented to examine the effects of the dam and environmental flow strategy on key hydrological, geomorphological and ecological attributes.

GLOSSARY

ANZECC Guidelines	Australian and New Zealand Guidelines for Fresh and Marine Water Quality
AusRivAS Assessment	Rapid prediction system used to assess the biological health of Australian rivers, using 'least disturbed' reference sites to derive OE50 taxa scores from lotic habitat
OE 50 Taxa Scores	Ratio of the number of macroinvertebrate families observed at a site compared to the number of families expected with greater than 50 per cent predicted probability of occurrence from lotic habitat
Band X	More taxa found than expected. Potential biodiversity hot-spot. Possible mild organic enrichment
Band A	Most/all of the expected families found. Water quality and/or habitat condition roughly equivalent to reference sites. Impact on water quality and habitat condition does not result in a loss of macroinvertebrate diversity
Band B	Fewer families than expected. Potential impact either on water quality or habitat quality or both resulting in loss of taxa
Band C	Many fewer families than expected. Loss of macroinvertebrate biodiversity due to substantial impacts on water and/or habitat quality
Band D	Few of the expected families remain. Extremely poor water and/or habitat quality. Highly degraded
SIGNAL	Stream Invertebrate Grade Number Average Level. Scores assigned to each taxa on basis of their response to chemical changes in the environment. Grade values range from 1 to 10, with a value of 1 indicating taxa tolerant to chemical pollution and a value of 10 indicating a sensitive family
Diadromous	Fish that migrate between fresh and salt water at regular life history phase, in either direction, but not necessarily to spawn. Catadromous and amphidromous are sub-categories of diadromous
Catadromous	Fish that migrate from fresh water as adults to spawn at sea (or in estuaries)
Amphidromous	Fish that migrate between the fresh water and the sea (or estuaries) at a regular life history stage, but not directly to spawn
Extirpate	To become locally extinct
Lacustrine	Pertaining to lakes
Lotic	Freshwater habitat characterised by running waters
Lentic	Freshwater habitat characterised by standing waters

Potamodromous	Fish whose life history is contained entirely within fresh water. Migrations, if they occur, do so within the freshwater system
Reach 1	Reach of the Williams River from the upper reaches to the storage full supply level (FSL). Length: 34 km (main stem river length only)
Reach 2	Reach of the Williams River from the storage FSL to Tillegra Bridge. Length: 19 km (main stem river length only)
Reach 3	Reach of the Williams River from Tillegra Bridge to Glen Martin. Length: 63 km (main stem river length only)
Reach 4	Reach of the Williams River from Glen Martin to Seaham Weir. Length: 23 km (man stem river length only)
Reach 5	Reach of the Williams River from Seaham Weir to the Hunter River confluence. Length: 15 km (main stem river length only).
Run-of-River	Releases of water from storage via the natural river course
Thalweg	Line which follows the deepest part of a stream or creek
TL	Total length. The length of a fish from the tip of its snout to the end of its tail
TN	Total Nitrogen
TP	Total phosphorus

1.0 INTRODUCTION

1.1 Background

Connell Wagner, on behalf of Hunter Water, has commissioned The Ecology Lab to conduct an aquatic ecological assessment in relation to the proposed construction and operation of the Tillegra Dam on the Williams River.

The construction and operation of dams can cause a variety of impacts to river ecosystems. The proposed construction of Tillegra Dam would alter existing lotic habitats in the upper Williams River, transforming them to a much larger, contiguous lentic habitat. Under operational conditions, the project may alter lotic habitats downstream of the dam by changing the natural flow regime. The proposed dam would potentially create a barrier to aquatic organisms moving up and/or down the Williams River.

1.2 Aims

The broad aim of the aquatic assessment was to examine the potential effects of dam construction and operation on aquatic habitats and communities in the Williams River, above, within and below the proposed inundation area. The aims included:

- assessment of ecological status of the Williams River;
- identification of threatened and protected fish and aquatic macroinvertebrate species, populations and communities that may be present in the Williams River;
- identification of pest species in the Williams River;
- assessment of aquatic habitat and communities in reaches of the river to be inundated and in reaches both upstream and downstream of the proposed impoundment;
- predictions of impacts on dam construction and operation on ecology of aquatic habitats and communities;
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The aquatic ecology assessment included a review of existing information and a field survey. The field survey yielded:

- descriptions of representative habitats surveyed;
- snapshot view at representative locations of key water quality parameters;
- list of aquatic flora, fish and mobile invertebrates caught/observed at each site;
- AusRivAS measure of river health based on the assessment of aquatic macroinvertebrate assemblages in riffle and pool edge habitat.

1.3 Legislative Context

With reference to aquatic flora and fauna and habitat, the following statutory requirements are relevant to the Proposal:

- *Environmental Planning and Assessment Ac*t 1979 (EP&A Act);
- *Fisheries Management Act* 1994 (FM Act) and its Regulations;
- *Threatened Species Conservation Act* 1995 (TSC Act);
- *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act);

1.3.1 Environmental Planning and Assessment Act 1979

The proposed Tillegra Dam development is to be assessed under Part 3A of the *Environmental Planning and Assessment Act 1979* (EP&A Act). The dam is considered a critical infrastructure development, and as such, is of state planning significance. The Ecology Lab has used Parts 4 and 5 of the EP&A Act as guidelines for the aquatic ecology assessment, and as such the relevant sections of the *Fisheries Management Act* 1994, the *Threatened Species Conservation Act* 1995 and the *Environment Protection and Biodiversity Conservation Act* 1999.

1.3.2 Fisheries Management Act 1994

The *Fisheries Management Act* 1994 and its Regulations is administered by the Department of Primary Industries (DPI) and applies to habitat and aquatic flora and fauna that have the potential to be affected by the Proposal. The scope of work for The Ecology Lab in this project includes freshwater vertebrate and invertebrate species. The Act has recently been amended by the inclusion of provisions (listed in the *Fisheries Management Amendment Act 1997*) to declare and list threatened species of fish, endangered populations and ecological communities and key threatening processes.

1.3.3 Threatened Species Conservation Act 1995

The *Threatened Species Conservation Act* 1995 applies to terrestrial and aquatic flora and fauna and is administered by the Department of Environment and Climate Change Parks Services Division (DECC). The TSC Act 1995 includes endangered aquatic ecological communities and key threatening processes.

1.3.4 Environment Protection and Biodiversity Conservation Act 1999

Under the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)*, which is administered by the Department of Environment, Water, Heritage and the Arts (DEWHA), actions that are likely to have a significant impact on a matter of national environmental significance (NES) are subject to a rigorous referral, assessment, and approval process. In the aquatic environment the Act lists threatened species, ecological communities and key threatening processes; migratory species and Ramsar areas of national significance.

For the purposes of this report, species listed under the EPBC Act that would potentially be affected by the Proposal are assessed according to the EPBC Act 'Administrative Guidelines on Significance'. The assessments are usually used to assist in determining whether the proposed development should be referred to the Federal Minister of the Environment for a decision on whether approval would be required.

2.0 EXISTING INFORMATION

2.1 Information Sources

The library database of The Ecology Lab, the unpublished literature and external databases (e.g. Web of Science) were searched for relevant material about water quality and aquatic biota of the Williams River.

A search of the 'BioNet' NSW Wildlife database maintained by DECC was done for the Williams River region (Web Reference 1). This search focused on fish and aquatic macroinvertebrate species found in the Williams River above Seaham Weir, including records of threatened or protected species listed under the FM Act and TSC Act. A search was also made for threatened species with relevance to the Proposal, listed under the EPBC Act (Web Reference 2). These searches were combined with other information about the known distribution of species to compile a list of fish and aquatic macroinvertebrate species potentially affected by the Proposal.

2.2 Physical Setting

2.2.1 Watercourses

The Williams River Catchment covers 1310 km^2 and is located in the northern section of the Hunter-Central Rivers Catchment Management Authority region. The Williams River and its tributaries, the Chichester and Wangat rivers originate on the Barrington Plateau, 120 km north-west of Newcastle.

The Chichester and Wangat rivers flow parallel and in a south-easterly direction into the 21,500 ML capacity Chichester Dam at 150 mAHD. Water is transported from the dam by pipeline to Dungog for treatment and then on to major city reservoirs in Maitland, Cessnock and Newcastle. Downstream of the dam, the Chichester River flows for 12 km to Bandon Grove where it joins the Williams River, approximately five kilometres downstream of Tillegra Bridge. In 2003 a rock ramp fishway was completed at the site where the water pipeline crosses the Williams River.

The headwaters of the Williams River are located at approximately 1,500 mAHD in the Barrington Tops National Park. Twenty kilometres downstream at Salisbury Gap (400 mAHD) the steep montane reaches of the Williams River leave the forested section of the catchment and enter cleared agricultural land. The upper reaches of the Williams River down to the full supply level (FSL) of the proposed Tillegra dam storage would be referred to as Reach 1 (Appendix 1). The FSL of the storage is at 150 mAHD which corresponds to an area of inundation that stretches 19 km from the north east of Underbank House downstream to the dam wall at Tillegra Bridge. This section of the Williams River would be referred to as Reach 2.

Downstream of the confluence with the Chichester River, the creeks entering the Williams River are relatively minor, draining the surrounding agricultural land. These watercourses include: Carowiry, Myall, Die Happy, Tabbil, Thalaba, Wallarobba and Black Camp creeks. The Williams River flows through the township of Dungog and then downstream to Mill Dam Falls at Glen Martin. The section of the Williams River from Tillegra Bridge to Mill Dam Falls will be referred to as Reach 3.

Mills Dam Falls marked the upstream extent of tidal influence prior to the construction of the Seaham Weir in 1967. Seaham Weir is located 23 km downstream of Mill Dam Falls and has created an impoundment with an estimated capacity of 4,300 ML. The section of the Williams River from Mill Dam Falls downstream to Seaham Weir – the Seaham Weir pool - will be referred to as Reach 4. Water is pumped from Seaham Weir via Balickera Canal to Lake Grahamstown, the major potable water supply for the lower Hunter region. Below the weir the Williams River continues in a southerly direction until it joins the Hunter River near Raymond Terrace, approximately 10 km downstream. This section of Williams River will be referred to as Reach 5. Freshwater flows from Reach 4 into Reach 5 via a submerged orifice fishway, through the weir gates when opened and over the top of the weir during flood flows (Department of Commerce 2008).

A number of wetlands exist along the lower Williams River region and extend approximately three kilometres upstream of Clarence Town. These include Seaham Swamp (*State Environmental Planning Policy No. 14 - Coastal Wetlands* 802b), Irrawang Swamp (SEPP 14 Wetland No. 803) and Richardson's Swamp.

2.2.2 Climate and River Flow Regime

The average annual rainfall in the Williams River catchment ranges from 1,600 mm in the headwaters to a low of less than 1,000 mm in the mid-valley around Dungog, increasing again closer to the coast (Chessman and Growns 1994). There is high inter-annual variability in rainfall. Inland areas have highest rainfall over December to March, with a secondary peak in June and the driest period is generally from July to September (Water Quality Task Group 1993, Chessman and Growns 1994). Flows in the Williams River reflect the seasonal pattern in rainfall with highs in March and low in September (Chessman and Growns 1994).

Flows in the rivers can also be affected by the abstraction of water for irrigation, particularly during drought periods (Brennan 1998). There are over 100 irrigation licences along the Williams River, but a large number are sleeper licences, not in general use but held for drought protection. There have been periods of zero flow recorded at the hydrographic stations at both Tillegra and Glen Martin.

In a study of macroinvertebrate fauna in the Williams River catchment Chessman and Growns (1994) recorded a range of flow velocities over riffle habitat sampled over Reaches 1 to 3 (Salisbury to Mill Dams Falls) of 0.15 – 1.92 m/s. Twelve of the fourteen sites sampled in this section of the Williams River recorded maximum velocities in excess of 1 m/s.

2.2.3 Vegetation and Landuse

The vegetation in the upper Williams River catchment is largely intact, lying within the Barrington Tops National Park and the Chichester State Forest. It includes subalpine woodland on the Barrington Plateau, a variety of rainforest types, and wet and dry sclerophyll forest at lower elevations (Ecosystem Task Group 1992). The snow gum (*Eucalyptus pauciflora*) is found at elevations greater than 1,200 mAHD, with the associated mountain gum (*E. dalrympleana*) becoming more prevalent with decreasing altitude. Cool temperate rainforest, found at 800 - 1,500 mAHD, is characterized by Antarctic beech (*Nothofagus moorei*). Dry sclerophyll forest covers the majority of this part of the catchment, particularly on lower altitude sites and exposed ridges (Ecosystem Task Group 1992).

In the lower valleys the natural forest cover has been almost entirely cleared and replaced by pasture for grazing by beef and dairy cattle. The clearing of floodplain forests occurred during the expansion of cropping and grazing in the mid nineteenth century, which probably had the initial effect of increasing run-off and flood peak discharges (Brooks *et al*. 2004). The Williams River was then further modified by flood mitigation works from the 1950s onwards to maximise channel capacity and flow velocity (Brooks *et al*. 2004). The programs included channel straightening and extensive desnagging (the removal of large woody debris and in-channel vegetation). Various engineering works were initiated to address the resulting channel instability, including the bulldozing of channel bars, the removal of gravel armour and boulders from riffles and the planting of exotic trees. There was evidence that the channel modifications have led to an erosion of downstream riffle crest as cease-to-flow height of the Williams River has fallen by 0.85 m in some areas since 1955 (Brooks *et al*. 2004).

2.3 Water Quality

Water quality in the Williams River has been monitored by Hunter Water Corporation and the (then) Department of Water Resources since 1972. Current key water quality stations are located at Tillegra, Glen William, Glen Martin, Boags Hill, and later, at Seaham Weir, (Water Quality Task Group 1993). The Environmental Protection Authority and the Hunter Water Corporation conducted a separate water quality assessment from July 1992 to August 1993.

Water quality was considered excellent in the forested, upper reaches of the Williams River, with a gradual deterioration in some variables downstream, and a more marked change associated with the impoundment behind Seaham Weir (Chessman and Growns 1994, Water Quality Task Group 1993). Total phosphorus (TP) levels increase downstream from Tillegra to Boags Hill (median values rising from 0.022 to 0.063 mg/L), with concentrations downstream of Glen William greater than 0.05 mg/L over 50 per cent of the time. These values were often in excess of the ANZECC guidelines upper limit of 0.025 mg/L for the protection of aquatic ecosystems in lowland NSW coastal rivers (ANZECC 2000). The major source of the nutrient load in the lower Williams River was thought to be diffuse agricultural landuse (Water Quality Task Group 1993).

Algal growth was thought to be phosphorous limited and Chlorophyll *a* levels were found to be moderate to high (Water Quality Task Group 1993). At Boags Hill station Chlorophyll *a* levels fluctuated between 5 – 15 µg/L, with periodic peaks reaching 60 µg/L. ANZECC guidelines recommend an upper limit of Chlorophyll *a* of 3 µg/L for coastal lowland rivers in NSW. Blue-green algae blooms occurred in the summer of 1990/91 in the Williams River from Clarence Town to Seaham Weir. The blooms were initially dominated by the genus *Anabaena,* but later on *Microcystis* was also detected (Water Quality Task Group 1993). Tests showed that blooms possessed some toxicity and public warnings were made by then Hunter Water Board and Department of Health and Department of Water Resources.

Turbidity within the Williams River was generally low to medium (5 – 50 ntu), which is within the ANZECC guidelines of 6 – 50 ntu. Turbidity could be high during high flow events (greater than 50 ntu), however sustained high turbidity was not a problem (Water Quality Task Group 1993). Faecal coliform levels were not high enough to prevent most uses (excepted untreated domestic use) but periodic high levels have been recorded, particularly in lower reaches and associated with wet weather runoff (Water Quality Task Group 1993).

Conductivity measured at the gauging stations varied from 190 µs/cm at Tillegra (median) to 260 µs/cm at Glen Martin which is within the guidelines suggested by ANZECC (Water Quality Task Group 1993, ANZECC 2000). The Williams River had a slight trend of increasing electrical conductivity going downstream and the major source of ions is believed to be local geological structures.

With the exception of iron, manganese and aluminium, metal concentrations were generally low relative to NH&MRC potable water guidelines. There were three exceptions and all coincided with periods of high turbidity (i.e. high flow) which is expected as metals are particle associated (Water Quality Task Group 1993).

The Dungog 2004 State of the Environment report (2004) concluded that water quality in the Williams River had been relatively consistent from the early 1990s to 2004, showing no improvement or worsening. Water quality was considered to be generally good, but with elevated Total Phosphorus (TP) and Total Nitrogen (TN), making conditions in the lower Williams River favourable for algal blooms when conditions were suitable (i.e. when temperatures were warm and flows low).

2.4 Riparian and Aquatic Vegetation

Previous surveys within Barrington Tops National Park observed riparian vegetation along the upper Wiliams River to be in excellent condition (Chessman and Growns 1994). Downstream of the National Park the riparian and instream aquatic vegetation has been affected by human activities, such as clearing, erosion and livestock access.

The native riparian vegetation along the reach of the Williams River from north of Salisbury downstream to Tillegra was characterised by the river she-oak (*Casuarina cunninghamiana*), *Angorphora floribunda* and the water gum (*Tristaniopsis laurina*) (Ecosystem Task Group 1992). Further downstream to Dungog, *A. floribunda* dominated, along with *Acacia* spp, *C. cunninghamiana*, and the cabbage gum (*Eucalyptus ampifolia*). At Clarence Town, these species were joined by ironwoods (*Waterhousia floribunda*), swamp she-oak (*Casuarina glauca*), Sydney blue gum (*Eucalyptus saligna*) and bottlebrush (*Callistemon* sp.). Downstream to Seaham Weir native riparian assemblages are comprised mainly of *C. glauca, A. floribunda,* forest red gum (*Eucalyptus tereticornis*), *E. saligna* and the paperbarks (*Melaleuca linariifolia* and *Melaleuca styphelioides*). Many of these latter species, including the broad-leaved paperbark (*Melaleuca quinquenervia*), were also associated with local wetlands.

The common reed (*Phragmites australis*) was common throughout the Seaham Weir pool and *Lomandra longifolia* is found on the banks of the Williams River throughout most of its range (Ecosystem task group 1992). Other aquatic species include; the water fern (*Azolla filiculoides*), the sedges (*Isolepsis nodosa, Schoenus nitens, Eleocharis sphacelate*), *Ottelia ovalifolia*, the water primrose (*Ludwigia peploides* ssp. *montevidensis*), water ribbons (*Triglochin procerum*) and cumbungi (*Typha orientalis*) (Ecosystem Task Group 1992). Chessman and Growns (1994) identified extensive beds of *Elodea canadensis* and *Vallisneria* sp. in the Seaham Weir pool. *E. canadensis* was also observed upstream of Dungog and *Microphyllum* sp. occurred in riffles in a number of sites.

Freshwater alga has been observed along much of the Williams River (Dungog SOE 2004). The thick growth at some sites may be indicative of nutrient enrichment, particularly weedy taxa such as *Compsopogon* sp. (Dungog SOE 2004). In Salisbury, heavy growths of *Melosira* sp. were observed. *Cladophora* sp. occurred in high biomasses downstream of Salisbury at Toonumbue, Munni Bridge, Tillegra Bridge and Mill Dam Falls (Dungog SOE 2004).

Compsopogon sp. was present at Bandon Grove and further downstream at Mill Dam Falls. Thick growth of epiphytes such as *Spirogyra* sp. and *Oedogonium* sp. were recorded on *Vallisneria* sp. along the Seaham Weir pool (Dungog SOE 2004).

Throughout the course of the Williams River downstream of Barrington Tops National Park the riparian vegetation has been cleared from sections of riverbank and weed species occur frequently, dominating some areas. Common weed species include: the small-leaved privet (*Ligustrum sinense*), Lantana (*Lantana camara*), willow (*Salix* spp.), blackberry (*Rubus procerus*), camphor laurel (*Cinnamonum camphora*) and vines such as morning glory (*Ipomoea indica*) and *Andredera cordifolia* (Ecosystem Task Group 1992). Prickly pear (*Opuntia stricta*) was present in the main river area north of Dungog and downstream at Clarence Town. Ground cover and annual weeds included: crofton weed (*Eupatorium adenophorum*), mist flower (*Eupatorium riparium*), stinking roger (*Tagetes minuta*) and Noogoora burr (*Xanthium chinense*) (Ecosystem Task Group 1992).

The aquatic weed, water hyacinth (*Eichhornia crassipes*) was present in lentic environments in the lower part of the Williams River catchment, such as farm dams, lagoons and wetlands, including the Seaham Swamp. Water hyacinth has been listed as a Class 4 weed in Dungog which requires that the "growth and spread of the plant must be controlled according to the measures specified in a management plan published by the local control authority". Alligator weed (*Alternanthera philoxeroides*) was first observed in the Williams River in 1993 and is currently spreading upstream at a rate of ~ 1 km/yr, with its current upstream limit above Glen Oak (Web Reference 3). Alligator weed is a major threat to wetlands and rivers and is listed as a weed of national significance and a Class 2 weed in Dungog (under Noxious Weeds Act 1993), with the requirement that "the plant must be eradicated from the land and the land must be kept free of the plant" (Web Reference 4). It is thought to be spread by machinery used to clear drainage canals and perhaps also by recreational craft (Dungog SOE 2004). Other aggressive aquatic weeds include *Hygrophila costata* and *Ludwigia longifolia*, which can both form dense mats around the margins of freshwater lakes and slow moving watercourses (Dungog SOE 2004).

2.5 Aquatic Macroinvertebrates

The Williams River supports a substantial biodiverse aquatic macroinvertebrate fauna (Chessman and Growns 1994, Web Reference 5). In general, the assemblages in the forested upper catchment are considerably different to those found in the waters that flow through agricultural land. Studies have indicated that the macroinvertebrate assemblages within Reaches 2 and 3 were very similar, diverse and contained a range of sensitive species. However, communities in the Salisbury area of Reach 1, and the majority of Reach 4, have been more impacted by habitat disturbance, such as bank erosion, siltation, loss of riparian cover and reduced water quality and flow velocity.

Following outbreaks of blue-green algae upstream of Seaham Weir in the early 1990s a survey was conducted on aquatic macroinvertebrate communities in the Williams River catchment as an indicator river health (Chessman and Growns 1994). Up to six different habitat types (including riffles and pool edges) were sampled across 29 sites on the Williams, Chichester and Wangat Rivers. Eighteen of these sites were located in the section of the Williams River that corresponds to the present study area: three sites above the proposed area of inundation (but downstream of the forested Barrington Tops National Park, Reach 1), three sites within the proposed area of inundation (Reach 2), seven sites from

Tillegra bridge to Glen Martin (Reach 3) and four sites from Glen Martin to Seaham Weir (Reach 4).

The study found a generally healthy macroinvertebrate fauna in the Williams River catchment. Approximately 450 species of river invertebrates were recorded over the entire 1994 study area, including over 350 species of insects, 35 species of mites, seven species of crustaceans (including the crayfish *Euastacus spinifer*, two shrimp, *Australatya striolata* and *Paratya australiensis*, and freshwater prawns from the genus *Macrobrachium*) and 16 species of molluscs, including the freshwater mussels *Alathyria profuga*, *Cucumerunio novaehollandiae* and two species of *Hyridella*. Many species were found only in the forested headwaters of the catchment (outside the current study area) and were apparently absent in agricultural streams. Sites in Reaches 2 to 3 were found to have a broad and similar range of taxa, with sensitive species well represented.

Riffle fauna from sites in Reaches 2 to 3 were similar although there were some differences in the relative abundances of the most common species. No riffles were sampled in Reach 4 as it is dominated by slow moving waters of the Seaham Weir pool and sensitive mayfly and caddis fly species were absent from riffles in Reach 1 (Salisbury area) which was instead characterized by tolerant midge species. Pool edge faunal assemblages were similar from Salisbury downstream to Mill Dam Falls (Reaches 1 to 3). The shrimp *P. australiensis* was abundant at all sites in Reaches 1 to 3. The caddisflies *Triplectides* spp. and the backswimmer (*Enithares bergrothi*) were particularly abundant from Salisbury to Dungog, whereas small water boatmen (e.g. *Micronecta batilla*) were abundant from Dungog to Mill Dam Falls, as were water striders and water scavenger beetles. All tolerant species were widely distributed in lowland rivers. The sites within Reach 4 (Glen Martin to Seaham Weir pool) had a lower diversity of macroinvertebrates and were characterized by tolerant, lowland species favouring still water.

Chessman and Growns (1994) identified bank erosion and bed siltation in the Salisbury area as the possible reason for the absence of sensitive species. Poor bank and bed conditions, reduced flow velocity and poor water quality combined to restrict macroinvertebrate fauna in Reach 4 to tolerant, lowland, still water species. Macroinvertebrate communities are sensitive to persistent local impacts such as bank degradation, bed siltation and low flow effects.

From 1994 to 1999 aquatic macroinvertebrates were sampled in the Williams River as part of a wider assessment of NSW river health (Web Reference 5). AusRivAS assessments and report cards have been produced for each of four sites, although only three are considered here as they are located in reaches of the Williams River potentially affected by the proposal.

Two sites sampled by the NSW River Health survey, one at Dungog and the other downstream at Thalaba Bridge, are both within Reach 3. At Dungog, macroinvertebrates had been sampled in both edge and riffle habitat during spring and autumn in 1997. Assessments were all in Band A (equivalent to reference condition) except for one edge sample, which was assessed as Band B (below reference condition and significantly impaired) due to the absence of three Hemiptera taxa, which subsequently collected in the following season. Pool edge habitat was sampled at Thalaba Bridge from spring 1994 to Autumn 1996 and the riffle was sampled in autumn 1995. AusRivAS assessments for all the samples at Thalaba Bridge were similar to that expected of reference sites (Band A).

The site downstream of Clarence Town corresponds to Reach 4 and was located in a section of the Williams River that was broad, deep and slow flowing with no riffle habitat. Pool edge habitat was sampled on one occasion in autumn 1997 and was assessed as Band C (severely impaired). The macroinvertebrate assemblage was much poorer than expected as none of the Diptera (true flies), Ephemeroptera (mayflies) and Odonata (dragonflies) that were predicted as present were collected.

In a meta-analysis of 42 sites in the Hunter River catchment, Chessman *et al.* (1997) ranked the Rock Crossing (Barrington Tops NP) and Thalaba Bridge sites (the only two from the Williams River in their study), as first and fourth respectively, using the SIGNAL grading system. The SIGNAL scores suggest the macroinvertebrate communities at these two sites were relatively undisturbed, containing a higher proportion of pollution intolerant taxa than the other sites.

Two undergraduate research projects at the University of Technology (UTS) have sampled macroinvertebrate assemblages in the Williams River (Edwards 1992, Cortez 2007). Edwards (1992) sampled riffle assemblages from two sites in the Barrington Tops National Park, two from Reach 2 (the proposed inundation area) and four from Reach 3. Multivariate ordination indicated that the six sites from Reach 2 and 3 were all very similar to one another relative to the two sites located in the heavily forested upper catchment. One sample from Underbank contained taxa found in the Barrington Tops sites, suggesting the downstream recruitment of these taxa from further upstream.

Cortez (2007) investigated the effects of river regulation in the wider Williams River catchment with sites on the Chichester as well as three sites on the Williams River. Macroinvertebrate communities from pool edge habitat were sampled during spring 2007 and AusRivAS assessments were made. The three sites on the Williams River were selected to represent, upstream of the proposed inundation area (Reach 1), the dam site at Tillegra Bridge (Reach 2) and downstream of the dam but upstream of the Chichester River confluence (Reach 3). Band assessments for the sites in Reach 1 and 2 were Band B (severely impaired and fewer families than predicted), indicating a potential disturbance resulting in a loss of some taxa. The site in Reach 3 had a Band A assessment. Cortez (2007) explained the differences in assessments of Williams River sites as being due to local variations in the quality of habitat (not large scale factors), such as degraded banks, hydrology and riparian completeness.

The various freshwater mussel species are an important part of the Williams River aquatic biota. *Alathyria profuga* has been observed in numerous studies in the Williams River and is believed to be a major part of the diet of animals like the water rat (*Hydromsy chrysogaste*) (Ecosystem Task Group 1992). *C. novaehollandiae* is found in gravel beds along the Williams River and has a highly synchronised spawning period in autumn, thought to be cued by falling water temperatures immediately following flood flows (Jones *et al*. 1986). The glochidia of *C. novaehollandiae* are not released until early spring, where upon they attach to the gills of fish for up to 12 months before becoming a free-living adult. Data on the abundance and distribution of freshwater mussels has been collected over the last ten years and is currently being analysed as part of a PhD thesis. This information was not available at the time of writing.

2.6 Fish

A literature and database search was conducted to obtain an inventory of fish fauna for the study area. Sources include the Australian Museum and NSW DPI collections, published distributions of freshwater fish and other surveys (Web Reference 1, McDowall 1996, Gehrke 1997, Harris and Gehrke 1997, Brooks *et al*. 2004).

The published literature indicated that thirty seven species potentially existed within the study area (Reaches 1 to 4, Table 1). Three of these species are exotic: mosquitofish (*Gambusia holbrooki*), goldfish (*Carassius auratus*) and carp (*Cyprinus carpio*). Although an Australian native, the freshwater catfish (*Tandanus tandanus*) did not occur historically in the Williams River but are believed to have been translocated from western part of their distribution (Pusey *et al*. 2004). No fish species are listed as threatened or protected species under the FM Act or the EPBC Act. The Ecosystem Task Force (1992) reported that the silver perch (listed as Vulnerable in the FM Act) were present in the Williams River above Seaham Weir but this is believed to be erroneous (see Section 2.7.1 below).

At least 16 species have been identified from collections made in the Williams River upstream of Seaham Weir (Table 2).

The majority of the 21 species not identified in surveys - but whose published distribution includes the region of the study area - usually inhabit brackish waters, but can also be found in the lower reaches of freshwater rivers. These include many of the gobies (Gobiidae), estuary perch (*Macquaria colonorum*), glassfish (*Ambassis marianus*), pacific blue-eye (*Psuedomugil signifer*), sand mullet (*Myxus elongatus*) and fan-tail mullet (*Valamugil georgii*). The absence of these species from survey may reflect a lack of sampling in the lower reaches of the Williams River, above Seaham Weir. The single fish record from Reach 4 was an Australian bass, which was an isolated Australian Museum record and was not part of a larger NSW DPI survey or research. Alternatively, these species may not have negotiated passage through submerged orifice fishway at Seaham Weir. The fishway is a type originally designed to facilitate the upstream passage of strong swimming northern hemisphere salmonids. It has a steep gradient (1:5) and a head loss of 0.3 m at each pool which generates maximum velocities of 2.4 m/s and high turbulence (Department of Commerce 2008). Small and weak swimming species may not be able to ascend this type of fishway (Mallen-Cooper and Brand 2007) and the surface swimming mullet may have behavioural barriers to using the fishway's submerged openings.

The Ecosystem Task Force (1992) reported that the estuary perch and brown trout (*Salmo trutta*) were present in the study area, which is feasible based on the published distribution for both species (McDowall 1996). However, there is no record of brown trout ever being stocked in the Williams River catchment so it is unlikely to be present apart from potentially isolated specimens released without authorisation (NSW DPI 2003a). Estuary perch inhabit tidal waters and can be found well upstream into freshwater, but usually only in the southern part of their range, south of the main distribution of Australian bass (*Macquaria novemaculeata*)(McDowall 1996). Given the local abundance of bass it is speculated that estuary perch may not venture far upstream into the fresh reaches of the Williams River.

The sole record of the giant herring (*Elops hawaiensis*) from Reach 1 is possibly erroneous or at least very rare. Adults inhabit coastal waters, bays and estuaries. The pelagic juveniles drift into estuarine habitat and may enter lower freshwater areas (McDowall 1996). It is unusual for an individual to be recorded as far upstream as Salisbury. Excluding giant herring, the fish assemblage in the study area is represented by 15 species that have been physically identified in collections. Undifferentiated records denoted as *Hypseleotris* sp. could be the fire-tailed gudgeon, which is predicted to be present in the region, but they could also be the empire gudgeon, which has been observed in the Williams River, therefore these entries were not counted as a separate species.

The fish assemblage in the region of the proposed dam storage (Reach 2) is characterized by Australian smelt (*Retropinna semoni*), Cox's gudgeon (*Gobiomorphus coxii*), long-finned eel

(*Anguilla reinhardtii*), Australian bass and freshwater catfish (*Tandanus tandanus*), whilst the other species do not appear as common. Brooks *et al*. (2004) surveyed fish twice a year over two years during an experimental re-snagging of the Williams River at Munni (Reach 2). From 177 replicate samples taken with an electrofisher, they recorded 13 species which included 1656 smelt, 546 Cox's gudgeon, 445 long-finned eel, 149 bass, 57 catfish and 16 sea mullet (*Mugil cephalus*). Other species, such as short-finned eel (*Anguilla australis*), Gambusia, striped gudgeon (*Gobiomorphus australis*), flathead gudgeon (*Philypnodon grandiceps*), freshwater herring (*Potamalosa richmondia*) and freshwater mullet (*Myxus petardi*) were only recorded only once or twice during the entire study.

Thirteen species (excluding giant herring) have been recorded within the proposed inundation area (Reach 2). There are apparently no DPI survey sites further upstream in Reach 1 and as such the records of these species in Reach 2 represent a minimum in the upstream extent of their distribution. Bass, for example, travel extensively upstream and have historically reached altitudes of 600 m in the Hawkesbury River (Table 3; McDowall 1996, Pusey *et al*. 2004). In the absence of barriers to passage, this upper limit of bass distribution in the Williams River corresponds to upstream of Munni and possibly into the Barrington Tops National Park. Similarly, the smaller Cox's gudgeon, which is rarely found close to the ocean, can range into mountainous areas and attain altitudes of at least 700 m (Table 3; McDowall 1996). Seven other species have been recorded at altitudes greater than 150 mAHD which would position the upper limit of their distribution in Reach 1 (Table 3). Although the climbing galaxias (*Galaxias brevipinnis*) is also not expected to occur in the region there was a record of two individuals collected by the Australian Museum in 2001 in the vicinity of Jerusalem Creek in the Barrington Tops National Park, to the east of Lake Chichester close to the catchment border (Web Reference 1). The climbing galaxias has not been recorded in the upper Williams River. Although putatively amphidromous this species can survive and reproduce in landlocked situations, which would explain its possible existence above the Chichester Dam. The low abundances of other taxa recorded at Munni may indicate that they are near the upper extent of their distribution. The bullrout (*Notesthes robusta*) has only been sampled as far as Dungog and is usually not found more than 50 km from the coast or above 60 mAHD (McDowall 1996, Pusey *et al*. 2004).

Of the 15 species that have been sampled in the entire study area, 10 species have diadromous life histories, moving between freshwater and estuarine/marine habitats at some point during their life (Table 3). Seven species have catadromous life cycles, which is they migrate from freshwater to estuaries or marine water to breed. Following spawning, adults migrate upstream, unless like eels they suffer significant mortality following spawning. Following development in the estuaries, juveniles also migrate upstream into freshwater habitat (McDowall 1996). Australian bass is a common catadromous species and is a very popular recreational fishing target. Bass migrate downstream from May to August to spawn following cues provided by flooding or high flows. Adult males remain downstream in estuarine waters whilst the females migrate back upstream into freshwater so that the population is sexually segregated during non-breeding season (McDowall 1996). Juveniles migrate upstream from spring through summer. The bullrout is thought to be catadromous but tiny juveniles have been found upstream of dams, suggesting that its life cycle can be completed in freshwater (McDowall 1996). Three of the gudgeon species have amphidromous life histories that involve movement between freshwater and estuarine habitats but not for the purpose of breeding. The larvae or juveniles are washed downstream into estuarine habitat where they develop and later migrate back upstream. However, of these three species, Cox's gudgeon can apparently complete its life cycle in freshwater, without their larvae being washed downstream into estuarine habitats (McDowall 1996).

It has been reported that the abundance of sea mullet and freshwater herring (both catadromous) was much lower in the Williams River compared to the adjacent Hunter River, which has no tidal weir (Department of Commerce 2008). A previous study has demonstrated the negative effect salmonid fishways have had on the upstream population of a congeneric species of freshwater herring (Mallen-Cooper and Brand 2007). As a surface schooling fish it is possible that the sea mullet has difficulty or behavioural barriers to negotiating passage through the submerged opening of the Seaham Weir fishway. At present, fish passage at Seaham Weir is possible for larger fish during flooding flows when the weir is submerged or through the weir gates during releases (but only when the head differential is ~ 0.1 m). Passage through the fishway is possible for smaller fish at high tides and low pool levels, when the head differential (headwater : tailwater) approaches zero or even becomes negative (Department of Commerce 2008). On such occasions the velocity inside the fishway declines, or even reverses, facilitating upstream passage, however the loss of freshwater outflows can make the fishway entrance harder for fish to locate.

Of the non-diadromous species, smelt and flathead gudgeon have been known to make facultative potamodromous and amphidromous movements and have been observed descending fishways into estuarine habitats (Pusey *et al*. 2004).

2.7 Threatened Species, Populations, Communities and Key Threatening Processes

2.7.1 Threatened Species

There are no listed threatened or protected species of fish or aquatic invertebrates in the Williams River upstream of Seaham Weir. The following species are present in the region (but not the study area where they may potentially be impacted by the proposal) or may have been erroneously reported as being present within the study area.

2.7.1.1 Silver perch (*Bidyanus bidyanus*)

The Ecosystem Task Group Report (1992) reported silver perch in a list of fauna present in the Williams River above Seaham Weir. The species is listed as Vulnerable under the NSW FM Act. The natural distribution of the silver perch is in the Murray Darling River system and this does not include the coastal rivers of NSW (NSW DPI 2003). Silver perch have been artificially stocked within the Hunter River catchment (e.g. in Glenbawn Dam), and the species has been collected from Lake Glenbawn and Lake St. Clair (NSW DPI 2003). However there are no collection records for this species in the Williams River catchment, nor are there DPI records of stocking in the Williams River catchment (Web Reference 6, NSW DPI 2003).

2.7.1.2 Adam's Emerald Dragonfly (*Archaeophya adamsi*)

Adam's emerald dragonfly is listed as Vulnerable under the FM Act. Only five adults have ever been collected from greater Sydney region (NSW DPI 2004). The larvae are found in small creeks with gravel or sandy bottoms, in narrow shaded riffle habitat with good riparian cover. The species is listed on the TSC website as being known to occur within the

Hunter sub-region within the Hunter-Central Rivers Catchment Management area. However DPI does not include the Williams River catchment as part of the potential distribution for the species, but instead includes the more southern watercourses within the Central Coast to the south (NSW DPI 2004).

2.7.1.3 Isopod (*Crenocious harrisoni*)

The isopod (*Crenocious harrisoni*) is listed as Protected under the FM Act. It is a small aquatic isopod found only in a spring that feeds Saxby's Swamp in the Barrington Tops National Park. Individuals are largely sedentary and the species does not have a dispersal phase, as such they are only found in a small area (NSW DPI 2006b). Threats to this species relate to local impacts on water quality and habitat. The species does not occur within the study area nor is it expected to be affected by the proposed development.

2.7.2 Threatened Populations and Communities

There are no listed threatened populations or communities of fish or aquatic macroinvertebrates species known to occur in the study area.

2.7.3 Key Threatening Processes

Threatening processes that are listed under the FM Act relevant to the proposed Tillegra Dam construction and operation include:

1. The removal of large woody debris from NSW rivers and streams;
2. The degradation of native riparian vegetation along New South Wales watercourses;
3. The installation of instream structures (i.e. bridges and culverts) and other mechanisms that alter natural flow regimes of rivers and streams;

Threatening processes that are listed under the TSC Act relevant to the proposed Tillegra Dam construction and operation include:

1. Predation by the plague minnow (*Gambusia holbrooki*).
2. Alteration to the natural flow regimes of rivers, streams, floodplains and wetlands.

3.0 SCOPE OF FIELD STUDIES

3.1 Sampling Design

Sites suitable for undertaking a survey of aquatic habitats and biota were selected above, within and below the reaches of the Williams River to be inundated (Figure 1, Appendix 1). For the purposes of sampling design and site selection, the area of inundation was considered to be the reach of the river that would be inundated at full supply (FSL), which corresponds to 150 mAHD extending from near Underbank House downstream to Tillegra Bridge. Twelve sites were selected, distributed from upstream to downstream as follows:

- two sites in the river reach above the proposed area of inundation (Reach 1);
- four sites within the proposed area of inundation (Reach 2);
- two sites just below the dam wall but upstream of the Chichester River confluence (Reach 3);
- two sites downstream of the Chichester River confluence and upstream of Dungog (Reach 3);
- two sites downstream of Dungog but upstream of the Seaham Weir pool (Reach 3).

The spatial arrangement of the sampling sites allows for:

- An assessment of changes to aquatic habitats and biota upstream of the impounded river by comparing habitats and biota at two sites above the inundation area before construction to the same site after construction;
- A characterisation of aquatic habitats and biota that would be altered from lotic to lentic habitats (within the inundation area), by documenting aquatic habitats and biota at four sites within the inundated river reach. Some historical data are available for some of these sites;
- An assessment of the impact of dam construction, run-of-river (Run-of-River) transfers and environmental flow releases on the reaches below the dam. As these impacts are expected to be greater in magnitude in the reaches closest to the dam wall, the spatial distribution of sites represents a gradient of increasing distance away from the dam wall, with two sites close to the dam wall but upstream of the influence of the inflow of the Chichester River, and two sites close to the influence of the Chichester River. Data on aquatic habitats and biota at these four sites collected before construction would be compared to data collected after, and in some cases, historical data, to estimate operational impacts of the dam on these river reaches;
- Data from two sites further downstream collected before dam construction can be compared to data collected after construction and during operation to estimate the downstream impact of dam construction and operation.

Data at each site were collected on:

- aquatic habitat, including physical channel attributes and riparian and instream vegetation;
- water quality, including physico-chemical variables, faecal coliforms, chlorophyll *a*, metals, pesticides, suspended solids and nutrients;

- aquatic macroinvertebrates. AusRivAS assessments of aquatic macroinvertebrate assemblages are used as an index of river health;
- fish assemblages.

3.2 Site Selection Methodology

3.2.1 Site Selection Criteria

Sites were selected on the basis of:

- Sites were required to represent the full spatial extent of the Williams River relative to the proposed area of inundation (i.e. upstream, within or below inundation area in distance gradient from dam wall). The downstream spatial extent of sites selected was constrained by the absence of riffle habitat in the Seaham Weir Pool;
- Accessibility: Sites were required to be accessible within short timeframe, i.e. permission available to access private property and site could be reached in reasonable amount of time using four-wheel drive and access on foot;
- Aquatic habitats present: (i) Sites were required to contain riffle and pool edge habitat within a single 100 m reach (as required by AusRivAS methodology) for aquatic macroinvertebrate sampling. (ii) Sites were required to include fish habitat that was suitable to sample with bait traps and a backpack electrofisher;
- Water characteristics: Sites were required to contain sufficient flow to take water quality measurements and samples.

3.2.2 Site Selection Methodology

As a desktop task, provisional sites were selected based on a previous study in the Williams River (Chessman and Growns 1994) where aquatic macroinvertebrates had been sampled from a variety of habitats including pool edge and riffle habitat. Additional sites were provisionally selected from the relevant topographical maps that suited the spatial arrangement of the sampling design. Coordinates of these preliminary target sites were supplied to the helicopter operators to allow an efficient examination of the sites by air. On the 14th November 2007 an aerial inspection of the entire length of the Williams River was done by helicopter to examine the suitability of these sites and to identify new or alternate reaches that contained riffle and pool habitat. Digital video was taken of the Williams River during the entire flight. Areas with broken water indicating possible riffle habitat were marked by GPS and a description was made of surrounding features, including access issues. The provisional site locations were revised following viewing of the video.

Final assessment of site suitability was made visually on the ground after arranging access with landowners. If a site was found not to be suitable then an alternative nearby site identified from the video within that reach was located.

3.3 Sampling Methodology

3.3.1 Riparian, Channel and Environmental Inventory (RCE)

At each site, a standardised description of the adjacent land and the condition of riverbanks, channel and bed was recorded using a modified version of the Riparian, Channel and Environmental Inventory (RCE) (Chessman *et al.* 1997) (See Appendix 2). Habitat descriptors included:

- geomorphological characteristics of the waterways (e.g. gully, intermittent stream, major river; deep pools or gravel beds; waterways interconnecting with other waterways or wetlands upstream or downstream);
- flow regime of the waterways (e.g. intermittent or permanently flowing);
- types of land use along the waterway (e.g. industries associated with the river, recreational uses);
- riparian vegetation and instream vegetation (e.g. presence/absence, native or exotic, condition);
- presence of instream or offstream wetlands;
- substratum type (e.g. rock, sand, gravel, alluvial substrata);
- presence of refuge areas (e.g. wetlands nearby could be interlinked by the waterway during flow);
- presence of spawning areas (e.g. gravel beds, riparian vegetation, snags); and

presence of natural or artificial barriers to fish passage both upstream and downstream (e.g. weirs, dams, waterfalls, causeways);

The waterway at each site was classified for fish habitat according to the NSW Guidelines and Policies for Fish Friendly Roads (Fairfull and Witheridge 2003; Appendix 3).

3.3.2 Water Quality

Water quality was measured *in situ* at each site using a Yeo-Kal 611 probe. Physical-chemical properties included:

- electrical conductivity (ms/cm and µs/cm);
- salinity (ppt); temperature (^{0}C);
- turbidity (ntu);
- dissolved oxygen (mg/L and per cent saturation);
- pH;
- ORP (oxidation reduction potential: mV).

Alkalinity was measured *in situ* using hand-held titration cells from CHEMetrics. Two replicate measures of each variable listed above were taken from just below the water surface at each site, except for alkalinity, where only one replicate measure was taken. The physical-chemical properties at Boag's Hill (Seaham Weir pool) were measured every 0.5 m, from just below the surface to just above the bottom. Physical – chemical water quality data were collected at the same time as macroinvertebrate and fish sampling was undertaken. The parameters can be useful in interpreting results of the biota survey, especially alkalinity, which is used directly in the AusRivAS model.

Two replicate water quality samples were collected from selected sites to be analysed in a chemical laboratory for:

- faecal coliforms;
- chlorophyll *a*;
- nutrients;
- anions;
- suspended solids;
- pesticides;
- heavy metals.

The samples at Boag's Hill (Seaham Weir pool) were obtained by lowering a niskin bottle to the appropriate depth. The following table indicates water quality parameters sampled at each site.

Site	Physical-chemical parameters (portable probe)	Metals	Nutrients	Pesticides	Anions	SS	FC	Chl *a*
W1	✓	✓	✓	✓	✓	✓		
W2	✓	✓	✓	✓	✓	✓		
W3	✓							
W4	✓	✓	✓	✓	✓	✓		
W5	✓							
W6	✓	✓	✓	✓	✓	✓		✓
W7	✓							
W8	✓	✓	✓	✓	✓	✓	✓	
W9	✓	✓	✓	✓	✓	✓	✓	✓
W10	✓	✓	✓	✓	✓	✓		✓
W11*	✓	✓	✓	✓	✓	✓	✓	✓
W12	✓	✓	✓	✓	✓	✓	✓	✓
Boags Hill Top (Seaham Weir pool)	✓	✓	✓	✓	✓	✓	✓	✓
Boags Hill Bottom (Seaham Weir pool)	✓ (Profile with depth)	✓	✓	✓	✓	✓	✓	✓

Water samples were packed in eskies with ice and couriered to two laboratories for analysis. Temporal constraints regarding the time between sampling and testing, and courier deadlines, resulted in the water samples being collected on separate days to the *in situ* physical chemistry water data. The eight sites (W6, W8 – W12) selected for faecal coliform and/or Chlorophyll *a* were sampled on Wednesday 5th December. Sites W1, W2 and W4 (no faecal coliform and/or chlorophyll *a*) were sampled the next morning on Thursday 6th December 2007.

Water quality Site W11, sampled for metals, nutrients, anions, pesticides, suspended solids, faecal coliform and chlorophyll a, was a provisional site selected from the helicopter survey, located on the Williams River, just to the north of Dungog (Easting 383720 Northing 6415820). Due to logistical constraints, the water quality samples for laboratory analysis were collected prior to the planned sampling for biota and physico-chemical water quality variables at Sites W11and W12. Provisional Site W11 was deemed unsuitable for biota sampling due to the large amount of bank stabilization works that had taken place. Due to the logistical constraints imposed by timely collection and dispatch of Chlorophyll *a* and faecal coliform analysis there was no time to locate an alternative site in the area, therefore water samples were taken at provisional Site W11. A more suitable location for Site W11 was later selected just downstream of Thalaba Bridge (Appendix 1 Easting 383704 Northing 6406824), however no further sampling was possible at this site due to large flow events in the Williams River.

3.3.3 Macroinvertebrates

Aquatic macroinvertebrates in the pool edge and riffle habitats at ten (of the proposed 12 sites) were sampled within the spring period (15th October to 15th December) in accordance with the Rapid Assessment Method (RAM) based on AusRivAS (Turak *et al.* 2004). Due to increasing flow in the Williams River following several rainfall events, sampling for fish and macroinvertebrates could not be done at sites W11 and W12 (furthest downstream) during the AusRivAS spring window. At each site, the chemical and physical variables required for running the AusRivAS predictive model were also recorded. Dip nets with a mesh size of 250 µm were used to collect invertebrates from these habitats. Edge habitat is defined as areas along creek banks with little or no flow, including alcoves and backwaters, with abundant leaf litter, fine sediment deposits, macrophyte beds, overhanging banks and areas with trailing bank vegetation (Turak *et al.* 2004). Riffle habitat is an area of broken water with rapid current that has some cobble or bolder substratum (Turak *et al*. 2004).

At each site, the edge habitat of slow moving pools and riffle habitat in faster flowing broken water was sampled. The dip net was first used to disturb animals by agitating bottom sediments and suspending invertebrates into the water column. The net was then swept through this cloud of material to collect suspended invertebrates and surface dwelling animals. Samples were collected over a total length of 10 m, usually in 1-2 m sections, ensuring that all significant edge sub-habitats within each site were sampled (Turak *et al.* 2004).

Each RAM sample was rinsed in the net with local water to minimise fine particles and placed into a white sorting tray. Animals were removed from the tray using forceps and pipettes. Trained staff removed animals for a minimum period of thirty minutes. Thereafter, removals were performed in ten minute periods to a total of one hour, at which time removals would cease if no new taxa were found in a ten minute period. A full hour was usually required for removing animals. Care was taken to collect cryptic and fast moving animals in addition to conspicuous or slow moving specimens. The animals collected were placed inside a labelled jar containing 70 per cent ethanol and taken to the laboratory. Finally, debris remaining in the tray after processing was returned to the creek in the locality where the sample was originally collected.

The presence of larger mobile macroinvertebrates was also recorded during electrofishing.

3.3.4 Fish and Mobile Invertebrate Sampling

Electrofishing and bait trapping were used in appropriate habitats within each site to sample fish and mobile invertebrates. A seine net was used in sites which had suitable bed morphology (Sites W4 and W6). These techniques are non-destructive, and all but introduced pest species such as the mosquitofish (*Gambusia holbrooki*), were returned unharmed to the water.

At each site 10 bait traps were deployed. The traps used were rectangular in shape and approximately 350 mm long and 200 mm wide with an entrance tapering to 45 mm, with 3 mm mesh size throughout. Traps were deployed in shallow water habitats that included bare substratum, macrophytes and submerged snags. Traps were baited with approximately 70 ml of a mixture of chicken pellets and sardines and were left for approximately 3 hours.

Electrofishing is a commonly used, non-destructive technique for sampling fish in freshwater habitats such as creeks, drainage ditches and streams. The technique involves discharging an electric pulse into the water which stuns fish, allowing them to be easily netted, counted, identified and released. Electrofishing was done in riffles, shallow pools and beneath overhanging banks and vegetation. One staff member used the electrofisher, whilst a second handled a dip net and was primarily responsible for capture of stunned fish. Captured fish were placed into a fish box, filled with stream water, which was handled by a third person on the bank. The third person acted as a safety officer for the other two. Three replicate "shots" of approximately 90 seconds of continuous fishing time were done at each site. Fishing power (amps) was standardised across sites by adjusting voltage output according to conductivity of the water.

All fish caught were identified and released as quickly as practicably possible. Any fish that could not be identified in the field was euthanised with clove oil and then preserved in 10 per cent formalin solution and returned to the laboratory.

3.4 Laboratory Methods

3.4.1 Water Quality

Faecal coliform analyses were conducted by Sonic Food and Water Testing. Metal, pesticide, nutrient, anion, suspended solids and chlorophyll *a* analyses were done by the Australian Government National Measurement Institute.

Water Quality Parameters	Analysis Method
FC - Faecal Coliform	Thermotolerant (Faecal) Coliform Count - Australian Standard 4276.6 - 1995 by Most Probable Number Method
CA - Chlorophyll a	WL177
N - Nutrients, anions, suspended solids	
Chloride	NWD3_NWB14
Nitrogen-Total as N	NW_S9_B23
NOx	NW_B19
Sulphate	NWD3_NWB14
Suspended Solids	NS_S13
Total Kjeldahl Nitrogen	NW_B23_S9
P - Pesticides	NR_19

M - Metals (and TP)

Arsenic total	NT2_47_251
Cadmium total	NT2_47
Chromium total	NT2_47
Copper total	NT2_47
Lead total	NT2_47
Mercury total	NT2_47_244
Phosphorus total	NT2_47
Zinc total	NT2_47

No specific quality control procedures were reported by Sonic Food and Water Testing for the analysis of faecal coliforms. The Australian Standard used includes control procedures for the preparation of growth media, growth conditions and counting methods. All samples were received by the laboratory within the specified 24 hour holding time. Sonic Food 7 Water Testing holds NATA certification for the analysis of faecal coliforms. Differences between replicate samples collected at the same site ranged from 1,100 to 400 colony forming units per 100 ml, a range that could be expected to represent natural variation.

Quality control procedures for the analysis of pesticides used by NMI included blanks, duplicates and spikes. There was acceptable spike recovery for all pesticides and the relative percentage difference (RPD) was acceptable on all spikes and duplicates.

Quality control procedures for the analysis of Chlorophyll *a* used by NMI included blanks Recovery was 99 per cent for all samples.

3.4.2 Aquatic Macroinvertebrates

Animals in the AusRivAS macroinvertebrate riffle and edge samples were removed, identified using a binocular microscope, and counted to a maximum of ten animals as per the AusRivAS protocol. Taxa were identified to family level except for Araneae, Cladocera, Copepoda, Hydracarina, Nematoda, Nemertea, Oligochaeta and Ostracoda. Chironomidae were identified to sub-family level as required by the model. Some families of Anisoptera (dragonfly larvae) were identified to lower taxonomic resolution (species), because they could potentially include threatened aquatic species. Identification of animals was validated by a second experienced scientist performing QA checks on each sample. Any animal whose identity was in doubt was sent to the DECC for identification.

3.4.3 Fish

Fish that could not be identified in the field were returned to our laboratory to be identified. Specimens were examined visually, using a dissecting microscope or compound microscope, with the magnification used depending on that required for identification. Identifications were made using recent taxonomic keys and an extensive reference collection of preserved specimens held at The Ecology Lab.

3.4.4 Data

3.4.4.1 Data Entry

Field data and results of laboratory analyses were entered into Excel spreadsheets. Entered data were then checked for errors by a second staff member and corrections were made if required. Verified spreadsheets were then locked as "ready only" to prevent accidental overwrite.

3.4.4.2 Data Security

Copies of all field data sheets have been made and are filed in a separate location from the originals. Copies of all results sheets provided by external laboratories have been made and filed in a separate location from the originals. All data have been backed up daily and fortnightly.

All original data and results sheets will be held by The Ecology Lab unless requested otherwise by Connell Wagner.

3.5 Data Analysis

3.5.1. Water Quality

Water quality data were compared with the ANZECC (2000) water quality guidelines for the protection of aquatic ecosystems in upland and lowland rivers, which provide a schedule of trigger values for potential management response in freshwaters of south-eastern Australia. Upland rivers are defined as >150 m altitude (ANZECC 2000), therefore these guidelines would apply to Sites W1 and W2. Sites W3 to W10 are classed as lowland rivers.

3.5.2 Macroinvertebrate AusRivAS Models

The AusRivAS protocol uses a model to determine the environmental condition of a waterway based on comparisons to a reference condition developed in the model. Separate predictive models are available for use with data collected in autumn and spring and there is a combined model that uses data from both seasons. The individual season models have been used for this study. The AusRivAS model generates the following indices.

- OE50Taxa - The ratio of the number of macroinvertebrate families with a greater than 50 per cent predicted probability of occurrence that were actually observed (i.e. collected) at a site to the number of macroinvertebrate families expected with a greater than 50 per cent probability of occurrence. OE50 taxa values range from zero to slightly greater than one and provide a measure of the impairment of macroinvertebrate assemblages at each site (Appendix 11). Values close to 0 indicate an impoverished assemblage and values close to 1 indicate that the condition of the assemblage is similar to that of the reference streams. Values greater than 1.16 at pool edge or 1.18 at riffles indicate the observed assemblage has a greater diversity than reference streams.
- Overall Bands are based on OE50Taxa scores which indicate the level of impairment of the assemblage (Appendix 11). These bands are graded as follows.

  Band X = Richer invertebrate assemblage than reference condition;

Band A = Equivalent to reference condition;
Band B = Sites below reference condition (i.e. significantly impaired);
Band C = Sites well below reference condition (i.e. severely impaired);
Band D = Impoverished.

The lowest band score obtained for the two habitats within each site was taken as the overall condition (Overall BAND), as recommended by the AusRivAS protocol (Turak *et al.* 2004).

SIGNAL (Stream Invertebrate Grade Number Average Level) scores - biotic indices developed by Chessman (1995) as a means of determining environmental quality of sites based on the presence or absence of macroinvertebrate families. Grade numbers were assigned to each macroinvertebrate family or taxa based largely on their responses to chemical changes in the environment. Grade values range from 1 to 10, with a value of 1 indicating a family tolerant to chemical pollution and a value of 10 indicating a sensitive family. A revised set of grade values were (SIGNAL2) developed by Chessman (2003), and are used in this analysis.

Two SIGNAL scores were examined:

- OE0Signal index - the ratio of the observed to expected SIGNAL score per site for taxa that have a probability of occurrence of more than 0 per cent;
- O0Signal index – Observed SIGNAL2 score, average for all SIGNAL2 grades for taxa that have a probability of occurrence of more than 0 per cent;

This is calculated by averaging the SIGNAL2 grades, respectively, for all observed taxa and are equivalent to the 'raw' SIGNAL and SIGNAL2 score (as per Chessman 1995, 2003). SIGNAL/SIGNAL2 grades

- SIGNAL > 6 = Healthy habitat;
- SIGNAL 5-6 = Mild pollution;
- SIGNAL 4 – 5 = Moderate pollution;
- SIGNAL < 4 = Severe pollution.

4.0 RESULTS OF FIELD STUDIES

Field sampling of aquatic biota and water physico-chemical water quality variables was conducted at sites W1 to W6 from 26 – 28 November 2007 (Appendix 1). Figure 1 shows locations of sampling sites along the Williams River. Weather during this trip was overcast with scattered showers. The second round of field sampling was conducted from 3 – 6 December 2007. Aquatic biota and physico-chemical water quality variables were sampled at sites W7 – W10 from 3 – 4 December and water samples for laboratory analyses were collected from 5 - 6 December. There was heavy rainfall during this period and sampling became increasing difficult throughout the week, especially downstream of the confluence with the Chichester River. Due to increased flows and elevated river heights, sites W11 and W12 were not sampled for biota and water physico-chemical water quality variables. The AusRivAS protocol indicates that sampling for macroinvertebrates should not be done in rising or flooded river conditions (Turak *et al.* 2004).

4.1 Description of Sites Sampled

Table 4 presents RCE (Riparian, Channel and Environmental inventory) and fish habitat assessment scores for each site. RCE scores indicated that many of the sites were similar to one another with respect to channel morphology, with good riffle and pool edge habitat in Reaches 1 to 3. There was some variation amongst sites with respect to the integrity of the riparian vegetation and channel banks. The surrounding land use was generally agricultural, with pasture used for grazing dairy and beef cattle. GPS co-ordinates marking the upstream and downstream extents of all sites selected and sampled are given in Appendix 1. GPS co-ordinates for W11 and W12 are single points only. Due to high flow conditions sampling for macroinvertebrates was not possible at these sites and hence 100 m sites were never established with GPS points for upper and lower limits.

4.1.1 Upstream of Proposed Inundation Area

4.1.1.1 Site W1

W1 was the furthest upstream site, located north of Salisbury, and approximately 2 km downstream of the Barrington Top National Park at 300 mAHD (Plates 1a and 1b). The land adjacent to the site beyond the riparian strip had been cleared for agricultural use. The riparian vegetation was largely intact, composed of a mixture of native (*Casuarina* sp. and *Eucalyptus* sp.) and exotic species (Small Leaf Privet, *Ligustrum sinense*), 5 to 30 m thick and with breaks at intervals greater than 50 m. The channel substratum was composed of bedrock, boulders and clean stones with obvious interstices. Detritus present in pools was predominantly wood, bark and leaves. The site consisted of a pool section towards the upstream limit, which rounded a bend and flowed over a short riffle (consisting mostly of cobble, pebble and boulders). This then flowed into a larger pool and over a boulderfield riffle, with the downstream limit of the site underneath a wooden bridge. The channel had a modal width of 8 -10 m, a maximum depth of ~1 m in the pools and ~0.2 m over the riffle. The pools contained deep holes with some submerged woody debris. This reach of the Williams River provided major fish habitat (Class 1 waterway, Table 4).

The riffle and pool edge habitat were suitable for macroinvertebrate and fish sampling and therefore suit the requirements of the aquatic ecological assessment.

4.1.1.2 Site W2

Site W2 was located ~4 km downstream of Salisbury at 190 mAHD (Plates 1c and 1d). The adjacent land was used for grazing. The riparian vegetation was a mixture of native and exotic species, less than 5 m in width on the eroded eastern bank and almost absent on the western bank, composed of pasture grasses. There was moderate bank degradation caused by livestock access. The upstream end of the site was positioned in a large riffle that extended for nearly half the length of the site before the channel deepened into a pool section. The downstream extent of the site was marked by a fence across the channel. The substratum was composed predominantly of cobble and pebble with some boulders in the riffle. There was a considerable amount of fine green filamentous algae attached to rocks in the riffle section. Modal width was ~12 m and depth was ~1m in the pool and 0.2 m in the riffle. This section of Williams River provided major fish habitat (Class 1 waterway, Table 4). Upstream of the sites was an artificial river grading structure composed of large boulders. The eastern side appeared to have a series of pools to facilitate fish passage.

The riffle and pool edge habitat were suitable for macroinvertebrate and fish sampling and therefore for the requirements of the aquatic ecological assessment.

4.1.2 Within the Proposed Inundation Area

4.1.2.1 Site W3

Site W3 was located in the upper section of the proposed inundation area (150 mAHD, Plates 2a and 2b). The upstream boundary of the site was located upstream of a bridge in a pool section. A riffle occurred almost directly underneath the bridge, which then split and continued either side of an elevated cobble/pebble bed in the middle of the channel before forming a long pool at the bottom of the site. The riparian vegetation was a mixture of native and exotic species and approximately 5 m thick on average across the site. Around the bridge, and in the upstream portion of the site, the riparian vegetation was sparse and incomplete. Bank degradation was common in this section as cattle were not excluded from the river. Modal stream width was ~12 m and depth was ~ 1 m in the pool section and 0.2 m across the riffle. The channel substratum was composed predominantly of bedrock in the pool and clean cobbles and pebbles in the riffle. Where present, detritus was mainly wood and leaves with some fine silt in pool sections. Site W3 was considered to provide major fish habitat (Class 1 waterway, Table 4).

The riffle and pool edge habitat were suitable for macroinvertebrate and fish sampling and therefore suit the requirements of the aquatic ecological assessment.

4.1.2.2 Site W4

Site W4 was located at the confluence of Quart Pot Creek on the Williams River (120 mAHD). The top of the site was located in a pool (Plate 2c). The water course continued downstream into a riffle at the river bend before forming a large pool (where Quart Pot Creek entered the site), and further downstream the pool habitat transformed into another long riffle, where the site ended (Plate 2d). The surrounding land use was grazing for diary cattle. Riparian vegetation was a mixture of native and exotic species, of variable width (5 – 30 m) with regular breaks at intervals of 10 – 50 m. On the west side of the upstream pool was a large disturbed pebble/cobble bar. The land owner informed that there had been major government landscaping to this section of the channel in previous years. The channel substratum was composed predominantly of cobble and pebble with some boulders present in the riffle, bedrock in deeper sections of the central pool and sand bars sections in the shallows. Water was up to 1.5 m deep in pool and ~0.25 m over the riffle. The channel had a modal width of 12 m. The landowner reported that Australian Bass were relatively common in this reach and that NSW DPI (Department of Primary Industry) had sampled numerous times with an electrofishing boat. There was submerged woody debris present and macrophytes in pool and riffle. The watercourse at site W4 was considered to provide major fish habitat (Class 1 waterway).

The riffle and pool edge habitat were suitable for macroinvertebrate and fish sampling and therefore suit the requirements of the aquatic ecological assessment.

4.1.2.3 Site W5

Site W5 was located on the Williams River ~500 m upstream of the Munni Bridge (120 mAHD). The adjacent land use was agricultural. The riparian vegetation was a mixture of native and exotic species, of variable width (5 – 30 m) with regular breaks at intervals of 10 – 50 m. There was a considerable proportion of weed species such as small leaved privet and *Tradescantia fluminensis*. The upstream half of the site was a large pool, approximately 18 m wide (Plate 3a). The channel then narrowed into a riffle section (~10 m modal width, 0.20 m deep, Plate 3b). The site terminated at a set of logs in the channel, which had limited damming effect. On either side of the riffle were extensive cobble/pebble bars. There were some algae present and *Persicaria* sp. was observed along the edge of the riffle in the pebble bar. The watercourse at site W5 was provided major fish habitat (Class 1 waterway, Table 4).

The riffle and pool edge habitat were suitable for macroinvertebrate and fish sampling and therefore suit the requirements of the aquatic ecological assessment.

4.1.2.4 Site W6

Site W6 was located ~ 400m upstream of Tillegra Bridge (90 mAHD). The surrounding land use was grazing. The riparian vegetation was a mixture of native and exotic species, of variable width (5 – 30 m) but complete or without breaks. The banks appeared quite stable and no undercutting was observed. There was some devegetation on the western bank. The top of the site was situated in a pool section, which was 15 m wide and 0.5 m deep with a substratum of cobble and pebble (Plate 3c). Downstream the channel formed a riffle with a modal width of 12 m, depth of 0.2 m over cobbles and pebbles. The site ended in another pool section (Plate 3d). A small amount of algae was observed and dense patches of *Persicaria* sp. Although *Persicaria* is an aquatic macrophyte it was usually found at this site above the wetted width in pebble/cobble bars adjacent to the channel. The reach at Site W6 provided major fish habitat (Class 1 waterway, Table 4). Detritus observed in pool edge habitat was composed of wood and leaves.

The riffle and pool edge habitat were suitable for macroinvertebrate and fish sampling and therefore suit the requirements of the aquatic ecological assessment.

4.1.3 Downstream of Proposed Inundation Area

4.1.3.1 Site W7

Site W7 was located ~500 m downstream of Tillegra Bridge at 90 mAHD. The site was downstream of the proposed inundation area and upstream of the confluence with the Chichester River (located another 4 km downstream). The surrounding land use was grazing. Riparian vegetation was a mixture of native and exotic species, of variable width (5 – 30 m) with regular breaks at intervals of 10 – 50 m. Channel banks were loose in places, commonly void of vegetation and undercutting was observed at curves and constrictions. A pool section was located at the upstream extent of Site W7 (Plate 4a) and had a modal width of 20 m. The channel then formed a riffle followed by another pool section, and a final riffle at the bottom of the site. On the southern bank there was a long pebble/cobble bed above the wetted perimeter. The substratum of the channel was composed of cobble and pebble. There was little siltation and detritus was predominantly wood, bark and leaves. Little algal growth was observed and only a small number of macrophytes such as *Persicaria* sp. and *Juncus* sp were present. The watercourse at Site W7 was considered to provide major fish habitat (Class 1 waterway, Table 4).

The riffle and pool edge habitat were suitable for macroinvertebrate and fish sampling and therefore suit the requirements of the aquatic ecological assessment.

4.1.3.2 Site W8

Site W8 was located ~4 km downstream of the Tillegra Bridge at 80 mAHD. (Plate 4c). The site was downstream of the proposed inundation area and ~1.5 km upstream of the confluence with the Chichester River. The surrounding landuse was grazing. The riparian vegetation was a mixture of native and exotic species, of variable width (5 – 30 m) with regular breaks at intervals of 10 – 50 m. Banks were loose, heavy slumping had occurred in some places (Plate 4d) and commonly devoid of vegetation. The upstream boundary of the site occurred in a section of pool marked with a fallen tree (Plate 4c). Downstream of this was a riffle section followed by a run/pool on a bend, with the site terminating in another riffle section. Modal wetted width of the channel was 25 m. Modal depth over the riffle was approximately 0.15 m and the substratum composed of pebble and cobbles with some boulder. There were also some bars or deposits of sand and gravel in the very downstream boundary of the site. The landowner described the site as good for Australian bass fishing and that other fish observed included freshwater catfish and freshwater herring. The watercourse at site W8 provided major fish habitat (Class 1 waterway, Table 4).

The riffle and pool edge habitat were suitable for macroinvertebrate and fish sampling and therefore suit the requirements of the aquatic ecological assessment.

4.1.3.3 Site W9

Site W9 was located ~3 km downstream of the confluence with the Chichester River (but above the confluence of Die Happy Creek) and there was a noticeable increase in the volume of flow. The site was located between two artificial river grading structures. The surrounding land use was grazing. Riparian vegetation was a mixture of native and exotic species, of narrow width (less than 5 m) and fairly incomplete (breaks at intervals of less than 10 m). Banks were loose, slumping had occurred in places and clearing was common.

The upstream boundary of the site would have been a pool under lower flow conditions, but was a run in what developed as a flow event as a local rain event increased river discharge at the time of sampling. The channel had an extensive pebble/cobble bed on the north bank (Plate 5a). Slower moving water was found in edge habitat in a back pooling area situated off the north bank half way along the riffle. There were a number of macrophytes in this section such as *Baumea* sp., *Juncus* sp., *Persicaria* sp. and *Cyperus* spp. The wetted width of the channel was ~25 – 30 m but the section of pool edge habitat sampled had a modal width of 3 m and modal depth of 0.3 m. The substratum was composed primarily of silt, with some sand, pebble and cobble. There were a number of timber snags and considerable cover of detritus. The maximum depth over the riffle reached 0.8 m due to elevated flows and the substratum was composed of a mixture of cobble, pebble and boulder. The watercourse at Site W9 provided major fish habitat (Class 1 waterway).

The riffle and pool edge habitat were suitable for macroinvertebrate and fish sampling and therefore suit the requirements of the aquatic ecological assessment.

4.1.3.4 Site W10

Site W10 was located ~1 km downstream of Fosterton Bridge, straddling the confluence of Die Happy Creek at 70 mAHD (Plates 5c and 5d). The surrounding land use was grazing. Riparian vegetation was primarily native tree and shrub species, of variable width (5 – 30 m) with regular breaks at intervals of 10 – 50 m. The channel banks were firm with undercutting limited to a few curves. The upstream boundary of the site was a deep pool section following a curve in the channel. Water flow in the centre of the channel was fast due to the flow event at the time of sampling. Edge sampling took place along the slower water of the southern bank in cobble and pebble and vegetation further upstream. The riffle section further downstream was separated into two parallel sections by a pebble/cobble bar in the middle of the channel. The channel was lined by bedrock on the northern bank. The riffle on the southern side was sampled and modal width of the channel was 18 m. The substratum was composed of boulder, cobble and pebble. The watercourse at site W10 provide major fish habitat (Class 1 waterway, Table 4).

The riffle and pool edge habitat were suitable for macroinvertebrate and fish sampling and therefore suit the requirements of the aquatic ecological assessment.

4.1.3.5 Site W11

Site W11 could not be sampled for biota due to elevated river levels. Provisionally, Site W11 was located just downstream of Thalaba bridge (downstream of Dungog but upstream of Seaham Weir) at 30 mAHD. Beyond the riparian zone the surround land use was mixed native vegetation and pasture. There appeared to be a frequent alternation of riffle and pool sequences, beginning with a 40 m-long riffle downstream of the bridge and the majority of the pools located at and downstream of the bend in the river. These habitats appeared to be suitable for the requirements of the aquatic ecological assessment, but were unsuitable for sampling within the spring AusRivAS period due to a series of rain events in November and December which elevated water level and flow rates. Pool edge and riffle sampling has been conducted at this site for previous studies.

4.1.3.6 Site W12

Site W12 was located at Mill Dam Falls. The surrounding land use was grazing for dairy. As for Site W11, it appears that this site, for which pool edge and riffle sampling has been done for previous studies, contains suitable habitat for fish and macroinvertebrate sampling. However high river levels and elevated flow rates precluded sampling within the spring AusRivAS sampling period.

4.2 Water Quality

Mean (± S.E.) water quality parameters for physico-chemical variables, metals, organochlorine pesticides, nutrients, faecal coliform, chlorophyll *a*, anions and suspended solids are presented in Appendices 4 - 7. Raw water quality physico-chemical variables for Seaham Weir depth profile is presented in Appendix 8.

4.2.1 Physical Chemistry

Problems were experienced in the field taking conductivity and salinity measurements as the conductivity probe on the Yeo-Kal 611 probe worked intermittently. Water samples were collected and conductivity remeasured in the laboratory following repairs to the probe. All sites returned values very close, if not identical to values recorded in the field. The exception was Site W1. Higher conductivity and salinity values were recorded in the laboratory for Site W1 than in the field. Laboratory values: Salinity (ppt) = 0.26, Conductivity (µS/cm) = 534, Conductivity (mS/cm) = 0.52. The lower conductivity values recorded in the field were kept as they were much closer to previous values recorded in the area during other studies (Web Reference 5).

Physico-chemical water quality variables were measured at the same time biota were sampled. There are no values for Sites W11 and W12 as it was not possible to sample biota at these sites.

Mean pH was within ANZECC (2000) guidelines for all of the sites, except W1 which was only just outside the lower trigger value (Table 5). Dissolved oxygen values display the opposite pattern with all sites outside of the ANZECC lower trigger value, except for Site W1 which is within the guidelines for upland rivers (Table 5). There is a gradual decrease in dissolved oxygen levels downstream from Reach 1 to Reach 3. Dissolved oxygen at the surface waters in Seaham Weir pool were also outside the lower limit for the protection of aquatic ecosystems (Table 5). Levels decline rapidly from approximately 2 m depth, reaching almost zero by 5 m (Appendix 8).

Turbidity at all sites except Site W9 was lower than the upper trigger value for upland and lowland rivers (Table 5). Turbidity at Site W9 is not considered a problem at it was sampled during a flow event and recorded a value just outside the upper trigger value.

Conductivity in the Williams River was generally low. Sites in Reach 1 and the Seaham Weir pool were with the ANZECC guidelines, whereas all sites, except Site W5, within Reaches 2 and 3 recorded conductivities beneath the lower trigger limit for lowland rivers.

4.2.2 Nutrients and Chlorophyll *a*

Total phosphorus (TP) and NO_x (Nitrate and Nitrite) were above the ANZECC guidelines at the majority of sites sampled (Table 5). TP was within the ANZECC guidelines at Site W9 only, whilst the rest of the sites, representing Reaches 1 – 4, were above the trigger value for ecosystem protection. NO_x values were also within ANZECC guidelines at Site W9 and at Site W4, all other sites recorded values equal to or above the trigger value (Table 5).

Chlorophyll *a* and total nitrogen (TN) concentrations were predominantly within the ANZECC guidelines (Table 5). Exceptions were the surface waters at Seaham Weir pool which recorded chlorophyll *a* concentrations above ANZECC trigger values, and Site W12 which recorded TN values in excess of the guidelines (although this was due to one particularly high replicate value).

4.2.3 Metals and Trace Elements

Arsenic, lead, chromium and cadmium concentrations were within ANZECC trigger values for ecosystem protection at all sites sampled on the Williams River (Table 6).

Reaches 1 to 3 all recorded copper concentrations both above and below the ANZECC trigger values (Table 6). Results were not obviously variable but reflect the fact that the ANZECC trigger value is close to the detection limit of the analyses used (Table 6, Appendix 6).

Mercury concentrations in the Seaham Weir pool were just above the ANZECC trigger value (Table 6). It is impossible to discern whether mercury concentrations at the other sites are above or below trigger values for ecosystem protection as the trigger values are below the detection limits of the analyses used. All sites sampled within Reaches 1 to 3 recorded mercury concentrations below detection limits (Table 6, Appendix 6).

Concentrations of Zinc were in excess of ANZECC trigger values for ecosystem protection at all sites sampled (Table 6, Appendix 6).

Concentrations of Copper were in excess of ANZECC trigger values in some sites in all reaches (Table 6, Appendix 6).

4.2.4 Organochlorine Pesticides

The organochlorine pesticides chlorane, endosulfan, endrine, heptachlor and lindane all recorded concentrations below ANZECC trigger values at all sites sampled (Table 7).

Toxicity of sites with respect to DDT was impossible to determine, as although all sites had values below the detection limits of the analyses, the ANZECC trigger value for *slightly – moderately disturbed systems* was also lower than the detection limits of the analyses used (Table 7, Appendix 7).

ANZECC guidelines (2000) report there is insufficient data to derive reliable trigger values for the pesticides aldrin, DDE, dieldrin, endosulfan alpha, endosulfan beta and methoxyclor. ANZECC has published low reliability trigger values in freshwater for all these pesticides but cautions against their worth (Table 7). DDE and dieldrin concentrations at all sites were lower than ANZECC low reliability trigger values. Although aldrin, endosulfan alpha, endosulfan beta and methoxyclor all recorded concentrations below detection limits at all sites sampled, toxicity is impossible to assess against the ANZECC low reliability triggers values which are also below the detection limits of the analyses used for these pesticides (Table 7).

4.3 Aquatic Macroinvertebrates

AusRivAS sampling was done for spring 2007 from edge and riffle habitats for sites W1 to W10 in Williams River. Sampling within locations W11 and W12 could not be done within the designated AusRivAS period for spring 2007 due to elevated river flows.

4.3.1 General Findings

A total of 2324 individuals were collected from edge and riffle habitats comprising 85 different taxa from sites in Williams River (Appendices 9 and 10).

4.3.2 AusRivAS

A summary of results from AusRivAS Spring 2007 analyses is listed in Table 8, with the raw sample data for macroinvertebrate assemblages listed in Appendix 10.

Combined results from AusRivAS analyses for edge and riffle habitats showed macroinvertebrate assemblages were comparable to those of reference conditions for sites W1 – W6 (Band A). Sites W7 – W10, classed as Band B, had significantly fewer taxa than expected when compared to reference conditions, suggesting potential impacts on water quality and/or aquatic habitat (Coysh *et al.* 2000). However, it should be noted that sites W7 – W10 were sampled during elevated flows, particularly sites W9 and W10 which were located downstream of the confluence with the Chichester River. AusRivAS suggests optimal sampling be done at least two weeks after recent flood events, as high flows can affect the composition of macroinvertebrate communities (Coysh *et al.* 2000, Turak *et al.* 2004). AusRivAS assessments at sites W7 – W10 should be interpreted with some caution and the number of observed taxa should probably be considered a minima. Flows remained high during the remainder of the 2007 spring AusRivAS period and further sampling was not possible.

SIGNAL2 scores (Table 8) were representative of macroinvertebrate assemblages from sites with possible mild to moderate water pollution. SIGNAL2 scores were higher in riffle habitats indicating the presence of a greater proportion of pollution-sensitive species than pools. Similarities (Table 8) between the expected and observed SIGNAL scores (where OE0Signal index = ~1) demonstrated that the macroinvertebrate assemblages collected were consistent with assemblages expected of AusRivAS reference samples, suggesting that streams with this suite of physico chemical variables may generally contain more pollution tolerant macroinvertebrate fauna. This might be expected when AusRivAS reference sites represent 'least disturbed' conditions; i.e. the reference site(s) may be affected by broadscale anthropogenic disturbances such as agricultural and urban runoff, altered flow regimes and introduced species (Chessman, 2003), and would themselves have lower SIGNAL2 scores than undisturbed sites. Moreover, Chessman (2003) found high SIGNAL2 scores only where dissolved oxygen was high, and a number of physico-chemical water quality variables were low, including alkalinity, conductivity, nutrient concentrations, temperature and turbidity. Therefore, a low SIGNAL2 score can also result from several kinds of physico-chemical stress (Chessman, 2003).

4.3.2.1 Edge Habitat

A total of 1102 individuals were collected from edge habitats, comprising 72 taxa (Appendix 9). Numbers of taxa varied among sites, with sites W1 – W6 (26 – 34 taxa) generally having more diverse assemblages than sites W7 – W10 (22 – 25 taxa) (Appendix 9).

Macroinvertebrate assemblages from edge habitats were classified as equal to reference condition for most sites (Band A). Exceptions were sites W1 and W5 which were classed as Band X, where assemblages were more biologically diverse than reference sites, containing greater numbers of taxa than expected (OE50) (Table 8). Sites W7 and W9 were classed as Band B, due to the absence of several key expected taxa; including several midge fly larvae (Chironomidae), water striders (Gerridae) at both sites W7 and W9; freshwater shrimp (Atyidae), diving beetles (Dytiscidae) and mayfly larvae (Leptophlebiidae) at site W9; and freshwater mites (Acarina) and mayfly larvae (Baetidae and Caenidae) at site W7. This suggests an impairment of the macroinvertebrate assemblages at sites W7 and W9 from potentially degraded water quality and/or habitat (Coysh *et al.* 2000). However, the results at sites W7 and W9 should be treated with caution due to the elevated flows that coincided with sampling.

Sites generally contained macroinvertebrate assemblages with greater numbers of tolerant taxa than sensitive taxa (O0SIGNAL scores = 4 - 5) (Table 8), indicative of waters with moderate pollution (Chessman 1995). Exceptions were sites W9 and W10, which had SIGNAL2 scores <4, suggesting water with severe pollution (Chessman 1995). However, observed SIGNAL scores were similar to the expected SIGNAL scores based on reference samples, thus tolerant taxa may form a significant part of macroinvertebrate assemblages from reference sites (with similar predictor variables). Moreover, these values are based solely on those taxa used in the AusRivAS model, excluding a number of other taxa, some of which have high SIGNAL2 grades (e.g. Philopotamidae (8), Osmylidae (7), and Sialidae (5)).

4.3.2.2 Riffle Habitat

AusRivAS samples collected from riffle habitats contained a total of 1222 individuals, comprising 58 taxa (Appendix 9). Numbers of taxa per site ranged from a low of 19 at W8 up to 31 at W1, with most sites containing 22 – 28 taxa.

AusRivAS macroinvertebrate assemblages from riffles at sites W1 – W7 and W9 were assessed as being equivalent to refer reference condition (Band A). Sites W8 and W10 were classed as Band B (Table 8), indicative of possible impacts on aquatic habitat or water quality (Coysh *et al.* 2000). Several key taxa which were expected to occur at these two sites but were not observed included freshwater shrimp (Atyidae), fly larvae (Tipulidae and Simuliidae), Dugesiidae, stonefly larvae (Gripopterygidae) and caddisfly larvae (Hydrobiosidae) (Appendix 10). Again, it is possible that the absence of these taxa at sites W8 and W10 was due to the elevated flows that coincided with sampling.

SIGNAL2 riffle scores indicate that water quality may be affected by mild levels of pollution (SIGNAL2 scores 5 – 6) due to the presence of more pollution tolerant taxa. An exception was site W3 (Table 8) with a SIGNAL2 score of 6.1, indicative of a macroinvertebrate assemblage from clean waters (Chessman 1995). OE0SIGNAL scores were very close to 1, indicating that macroinvertebrates from 'reference condition' samples were exposed to similar water quality conditions (Chessman, 2003).

4.4 Fish

594 individual fish representing six species were caught from the 10 sites sampled on the Williams River using the electrofisher and bait traps (Table 9): Cox's gudgeon (n = 37, Plate 6a), striped gudgeon (n = 2, Plate 6b), flathead gudgeon (n =1, Plate 6c), Australian smelt (n =519, Plate 6d), long-finned eel (n =34), mosquitofish (n =2). All six species were caught with the electrofisher. Cox's gudgeon and smelt were caught in baits traps and only smelt were caught with the seine net (catching an additional >500 individuals).

Cox's gudgeon were caught at all 10 sites representing Reaches 1 to 3. Smelt and long-finned eel were caught at all sites except for Site W1 and Site W9 respectively. Striped gudgeon were caught at Site W4 and Site W7, the flathead gudgeon was caught at Site W2 and the mosquito fish were caught at Site W9.

Fish were recorded from 11 of the 100 traps set, and 28 of the 30 electrofisher replicate shots.

5.0 ASSESSMENT OF IMPACTS

5.1 Description of Proposal with Respect to Impacts on Aquatic Ecology

The Tillegra Dam Project would comprise the following components that relate to aquatic ecology:

- 76 m-high Dam wall and spillway;
- A multi-level offtake tower;
- A hydropower generation plant;
- A pipeline and pump station connecting Tillegra Dam to the Chichester Trunk Gravity Main (CTGM);
- Relocation and reconstruction of Salisbury Road (including construction of three waterway crossings);
- Ancillary works as required (such as potential recreational access areas, lookouts and related facilities).

The dam wall would be located just upstream of Tillegra Bridge. At full storage level (150 mAHD) the impoundment would flood the reach of the Williams River from the bridge, upstream to the north east of Underbank House.

River flow would not be impeded during construction. Environmental flows would be provided during the filling and operational phases of the project. As a starting point for analysis, the proposed environmental release strategy during the filling period would seek protect low flows with transparent releases to the 90th percentile exceendence and 60 per cent translucent releases from the 90th to 30th percentile exceendence. Within this base case, there is a contingency for a 2,000 ML/day flushing flow depending on water quality. Once the dam is operational, Run-of-River transfers would be released from Tillegra Dam, averaging approximately 360 ML/day and lasting 30 days, with extraction from upgraded pumps at Seaham Weir to transfer flows via the existing Balickera channel to Grahamstown Reservoir. Run-of-River transfers would commence at anytime that the full supply level of Tillegra Dam was greater than 90 per cent or at other times, when Grahamstown Dam was less than 40 per cent. Spilling flows would occur once the dam reaches full supply level (FSL).

The use of dams to regulate natural river flows has been demonstrated to have a number of impacts on aquatic ecology upstream and downstream of the dam structure (Gehrke and Harris 2001, Growns and Growns 2001, Bunn and Arthington 2002, Gehrke *et al*. 2002). Aquatic assemblages can be affected by changes to water quality, habitat, the natural flow regime and the creation of barriers to passage. Additionally, there are potential cumulative impacts arising from damming an already regulated river system. Five listed key threatening processes are relevant to the proposal (Section 2.7.3). The possible impacts associated with the Proposal are outlined below. They are divided into various subcategories based on (i) the stage of the development; (a) construction, (b) dam filling, (c) operational releases from the storage, and (ii) by reach (Reaches 1 – 4: see glossary). This process is addressed separately for each of habitat/water quality, fish and aquatic macroinvertebrates. Impacts are summarised in Table 13.

See the Environmental Flows and River Management report for a detailed description and assessment of the proposed environmental release strategy on the aquatic biota of the Williams River.

5.2 Impacts on Aquatic Habitats and Water Quality

5.2.1 Construction Phase

5.2.1.1 Reach 1 – Upstream of Storage

There would be limited impacts on aquatic habitats in Reach 1 as a result of dam construction. Possible impacts may be associated with the construction of the relocated section of Salisbury Road, although it is unknown how far these works would extend into the region of Reach 1, which would not be inundated by the proposed storage.

5.2.1.2 Reach 2 – Storage

The construction of the dam and the relocation of Salisbury Road are major works projects. Loss of riparian vegetation and instream woody debris is likely in the vicinity of the dam wall and any watercourse crossing of the relocated Salisbury Road. The loss of riparian vegetation and instream woody debris are listed key threatening processes (Section 2.7.3). Riparian vegetation is an important source of detrital plant matter and large woody debris. Its acts as a buffer, protecting the watercourse from the effects of landuse practices in adjacent areas and provides shade, cover and detrital material. Instream woody debris provides complex habitat for macroinvertebrates and particularly fish, including refuge from predation, habitat for prey and as damming structures that create pools. All riparian vegetation or instream woody debris along the Williams River in Reach 2 would be lost as this reach would be inundated during the reservoir filing phase of the proposal.

Major earthworks and run-off over unprotected spoil or cleared land may result in the mobilisation of sediments into the Williams River and its tributaries. Mobilised sediments would be transported to downstream reaches. An increase in sediment load can result in:

- loss of habitat. For example; a reduction of available deep water refuge areas for aquatic biota (pools) and smothering of important habitat features such as aquatic macrophyte beds, riffles and gravel spawning grounds.
- reduced water quality;
  - increased turbidity may result in a decline in light penetration and therefore primary productivity, including macrophyte beds,
  - an increase in associated nutrients which may encouraging algal growth and blooms,
  - contaminants (if present) bound in sediments could be released during suspension into the water column.

The likelihood and scale of impacts of an increased sediment load would depend on the amount of sediment mobilized into the water and over what period it occurs. The mobilization of sediments can usually be controlled with standard sediment control procedures for construction.

Changes to Reach 2 habitat are of little long-term consequence, as the 19 km reach within the storage area would be changed from a riverine habitat to a lentic habitat when the dam is operational. The level of impacts below the dam wall during construction and filling would be proportional to the magnitude and frequency of flows either diverted or released into habitats below the dam wall.

5.2.1.3 Reach 3 – Dam wall to Glen Martin

During construction river flows are to be diverted from the intake tower site, down a tunnel of 5.8 m diameter, to the outlet channel. All flows would pass through the diversion tunnel with the possible attenuation of large flooding flows only (greater than 10,000 ML/day).

Impacts on aquatic habitat downstream in Reach 3 may occur as a result of sediment mobilized at the dam wall construction site (Section 5.2.1.2). The likelihood and magnitude of an impact on habitat would decrease with distance downstream as sediment settles out of suspension.

5.2.1.4 Reach 4 – Glen Martin to Seaham Weir

The impacts on aquatic habitats in Reach 4 are similar to those outlined in Section 5.2.1.3. As Reach 4 is located further downstream, the likelihood and magnitude of any impact on aquatic habitats is expected to be lower than in Reach 3.

5.2.2 Dam Filling Phase

The duration of the dam filling phase would depend on rainfall within the Tillegra catchment following construction. Modelling a range of inflow scenarios indicates that the dam should reach FSL in 5 – 13 years.

5.2.2.1 Reach 1 – Upstream of Storage

There are unlikely to be any impacts on aquatic habitats in Reach 1 as a result of the reservoir filling.

As the reservoir fills, the lotic habitat forms of the Williams River in Reach 2, would be replaced by the lentic habitat of the storage. The impoundment would be characterized by still water which is favoured by carp, an introduced species. Carp have been sampled in the adjacent Hunter River catchment, and are predicted to be present in the Williams River (Table 1). Should carp become established in the proposed Tillegra storage and proliferate there is a possibility the species could colonize upstream into Reach 1. The foraging behaviour of carp can cause considerable damage to aquatic macrophytes and lower water quality through the resuspension of benthic sediments (Copeland *et al*. 2003).

5.2.2.2 Reach 2 – Storage

Upon completion of the dam wall river regulation would begin as flows are retained in the storage. The filling phase would result in the complete loss of 19 km of the Williams River and associated lotic habitat. Reach 2 contains high quality fish and macroinvertebrate habitat. It is comprised of riffles, runs and pools flowing over a predominantly cobble and pebble channel, with some bedrock, boulder and gravel substrata. This reach would be replaced with a 450,000 ML reservoir (FSL at 150 mAHD), with little established riparian or aquatic macrophyte habitat. Much of the land at 150 mAHD has been cleared for grazing, and contains exotic pasture grasses and annual weeds.

The physical and chemical characteristics of water in reservoir would be different to those of the relatively narrow, shallow Williams River. Eventually, the storage would stratify, with cold, deoxygenated water lying on the bottom. The storage would also be a sink for suspended sediment, bed material and organic carbon flowing in from the upper catchment. Water quality results revealed that all sites sampled in this reach had total phosphorus concentrations in excess of ANZECC guidelines (Table 5). The two sites tested for chlorophyll *a* were within ANZECC trigger limits, but flow velocity and water temperature may have been the limiting factors for algal activity. Other freshwater algae have been observed in this reach (Section 2.4). The stratified storage may develop conditions in summer suitable for blue-green algal blooms. Mitigation of potential algal blooms is being considered for the filling and operational phases of the dam in which destratification equipment is likely to be installed.

Artificial lentic environments, such as dam reservoirs, can provide habitat for fish provided they are managed appropriately. However, as for Section 5.2.2.1, should carp become established in the storage they would degrade the edge habitat, damaging macrophyte beds that may have developed and increasing sediment loads and turbidity. Wind generated waves in the storage may erode the unvegetated shores of the storage. The large lentic waters of the storage and the 76 m high dam wall would represent a large barrier between previously continuous lotic habitats.

5.2.2.3 Reach 3 – Dam wall to Glen Martin

At the commencement of the filling phase bulkheads will be fitted to the diversion tunnel. The inlet tower is constructed over the diversion tunnel. The inlet tower would not be able to make releases until the storage reaches 10 m depth, therefore from 0 – 10 m storage depth, a 61 cm diameter by-pass pipe parallel to the diversion tunnel would be used to make environmental releases. It has an 80 ML/day capacity with a 3 m head.

The proposed environmental release strategy is for transparent flows to the 90th percentile exceedence (7.4 ML/day) and for 60 per cent translucency for flows from the 90th – 30th percentile exceedence (7.4 ML/day - 100 ML/day). Sixty three megalitres a day would be released from the storage for all inflows in excess of 100 ML/day. The resulting discharge regime from Tillegra Dam would range from ~ 0 – 63 ML/day and would reflect the natural variability of inflows. There is a contingency for a 2,000 ML/day flushing flow depending on water quality.

The environmental release strategy during the filling phase is characterised by an increase in the frequency of low to moderate flows and the loss of high to flooding flows. The decline in median flow volume would lead to a concomitant reduction in velocity, depth, channel 'wetted width', flow variability, and the magnitude and frequency of elevated seasonal flows. The changes would be greatest in the 5 km section of Reach 3 from the dam wall to Chichester River as discharges from the Tillegra catchment represent all of the flow in this part of the Williams River. Further downstream the effects would diminish somewhat as the proportion of flow contributed by the Tillegra catchment decreases following inflows from the Chichester River and other smaller tributaries.

The reduction in the wetted width of the channel would result in the loss of a proportion of shallow riffles and gravel/sand bars in Reach 3, particularly in the broad low energy riffles above the Chichester confluence. These geomorphological forms are important habitat for variety of associated invertebrate and fish species. With an increase the proportion of low flows, natural and artificial barriers to fish passage in Reach 3 may become more problematic, fragmenting and/or reducing access to spawning and foraging habitat.

There would be minimal bedload transport during the filling phase in the upper section of Reach 3 down to the Chichester River junction (Gippel and Anderson 2008). The higher translucent flows should flush silt from the majority of riffles, although the 2,000 ML/day flushing flow may be required to remove fines that may accumulate in more stable pools. The accumulation of fines can smother habitat such as gravel beds, the interstices of pebble/cobble substrata, macrophytes and the surfaces of large woody debris. This should be offset upstream by the reduction of suspended sediment in flows discharged from the storage (Reach 2).

Macrophytes have been frequently disrupted in riffles and pools along the course of Reach 3 (Gippel and Anderson 2008). During the filling phase only the 2,000 ML/day flushing flow would be of sufficient magnitude to effect macrophytes, which may then encroach further into the channel.

Sites in Reach 3 have recorded total phosphorus (TP) levels in excess of ANZECC trigger values and the weir pool has experienced blue-green algal blooms in the past. A regime dominated by lower flows may decrease downstream water quality due to a reduction in flushing flows. Although the lower pool sections of Reach 3 would continue to receive inflows from the Chichester River and discharges from unregulated creeks that enter further downstream, which may help to minimize increases in algal activity.

The low flows may improve conditions for carp expansion upstream into Reach 3 where they can cause habitat degradation including increasing turbidity and damaging macrophytes.

5.2.2.4 Reach 4 – Glen Martin to Seaham Weir

The effect of the environmental release scheme on the flows in Reach 4 would be lower than in the upper sections of Reach 3 as the proportion of flow contributed by the Tillegra catchment is lower due to the inputs of environmental releases/spilling flows from Chichester Dam and discharges from unregulated creeks that enter further downstream.

The potential impacts of dam filling on aquatic habitat in Reach 4 would be similar to those outlined for Reach 3 in Section 5.2.2.3. Possible water quality problems associated with extended periods of low flow would increase as Reach 4 has a lower gradient, wider channel and slower flows. This reach also recorded TP levels in excess of ANZECC trigger values and has recorded blue-green algae blooms in the past. Frequency and severity of algal blooms may increase in this reach during the filling phase of Tillegra Dam.

A large component of flood flows from the Tillegra catchment would be intercepted by the storage thereby decreasing the frequency and duration of flow events that inundate adjacent wetland areas in the lower part of the reach. These ephemeral habitats can be utilized by fish, especially developing juveniles.

Lower flows and changes to the flow regime may diminish access to spawning and nursery habitat downstream of barriers such as Seaham Weir.

5.2.3 Dam Operational Phase

5.2.3.1 Reach 1 – Upstream of Storage

Similar to Section 5.2.2.1, there a few potential expected impacts on aquatic habitat following the operational phase of Tillegra Dam on Reach 1.

5.2.3.2 Reach 2 – Storage

By the time Tillegra Dam is operational the aquatic habitat would have transformed into lacustrine system. Reach 2 would continue to experience similar issues to those outlined in Section 5.2.2.2 (e.g. potential water quality problems and possible bank erosion from waves caused by wind and possible recreational use). With time macrophytes and riparian vegetation may colonize available areas, with the potential for the infestation of weed species. The substratum would tend to become dominated by sand and silts that accumulate in the storage rather than be carried downstream. The occurrence of algal blooms during summer months is expected to be an ongoing possibility.

The storage level may vary more than natural lake habitat depending on the combination of Run-of-River transfers, evaporation and inflows. Variation in the storage level may create variable habitat quality for fish and macroinvertebrates.

5.2.3.3 Reach 3 – Dam wall to Glen Martin

After three years of filling the Run-of-River transfers would commence. There would be no change to the underlying environmental release regime of transparent and translucent flows ranging from 0 – 63 ML/day. Based on the operational protocols for calling Run-of-River transfers, modelling has predicted there would be approximately 3 Run-of-River transfers a year, with a mean size of 362 ML/day and event duration of 30 days. After reaching near FSL spilling flows would commence and are predicted to occur 22 per cent of the year, with a mean magnitude of 461 ML/day.

The addition of Run-of-River transfers and spilling flows would create a bimodal flow frequency distribution with peaks at ~ 60 ML/day and again in the range of 250 – 600 ML/day (with a similar pattern to the distribution of peak flows). The frequency of flows within the 250 – 600 ML/day range is greater than the pre-dam period, therefore there is a reduction in the frequency of large flow events and also low to moderate flows. Unless care is taken to establish appropriate protocols for releasing Run-of-River transfers, change in flow distribution is predicted to be particularly marked during spring (and to a lesser extent summer), historically a season dominated by stable low flows, which would see an increase in fresh-sized flows due to the predicted uneven distribution of Run-of-River transfers across the year.

Median volume is therefore predicted to increase slightly relative to the historical flow regime (although mean and total flow would decline due to the reduction in larger flow events). Therefore, median velocity, depth and wetted width are expected to increase slightly relative to historical flows, although there would be a reduction in the magnitude of peak flows across much of their distribution. Constant groundwater 'leakage' from the Tillegra storage into Reach 3 would result in the loss of all cease-to-flow days along Reach 3, the majority of which occurred in the summer months. Changes to the flow of the Williams River relative to historical patterns - and resultant effects on habitat - would diminish somewhat downstream as the channel receives unregulated inputs from smaller tributaries and spilling flows from the Chichester Dam.

The operational release scheme should improve water quality in reaches 3 relative to the filling phase by providing larger, potentially flushing flows. Any encroachment of macrophytes into the channel should be reversed with the resumption of more disruptive flows responsible for structuring the pre-dam assemblage. Median wetted width is predicted to increase in Reach 3, particularly at the broader low energy riffles. Therefore the availability of riffles and gravel bars would increase relative to historic flows.

Flows capable of mobilising small particle sediments should restore areas of degraded habitat where silts and larger fines may have accumulated. The return of larger flows would also result in the resumption of bed transport in the upper section of Reach 3, although it is predicted to occur at a lesser rate due to the decline in frequency of high and flooding flows (Gippel and Anderson 2008). The environmental releases would be sediment-poor as upstream bed material would be trapped in the storage following construction. Riffles and gravel/sand bars would be scoured to the bedrock in unstable areas without any replenishing bed material. Scour could potentially occur down past the Chichester River which is also sediment poor, although further downstream unregulated creeks would add coarse sediment into the Williams River channel (Gippel and Anderson 2008).

5.2.3.4 Reach 4 – Glen Martin to Seaham Weir

The change to the flows of the Williams River during the operational regime would be experienced downstream in the Seaham Weir pool, but to a lesser extent than further upstream, due to discharges from the Chichester River and other smaller tributaries. The distribution of base and peak flows would not expected to be as bimodal in nature as at Tillegra. At Glen Martin, flow volume (ML/day) is predicted to decline for all peak flows from the 70^{th} – 0^{th} percentile exceendence. There would be a reduction in overbank flows and therefore in access to adjacent wetlands and floodplains.

Reach 4 has a lower gradient (and therefore flow velocities) than Reach 3 and as such is not expected to experience scour. There is little riffle habitat in this reach and there would be minimal, if any effect on wetted width of the channel.

It is not known if Run-of-River transfers and spilling flows would be sufficient replacement 'flushing' mechanism for the loss of historical large summer flood flows in the Seaham Weir pool, which may reduce the risk of eutrophication.

5.3 Impacts on Fish

5.3.1 Construction Phase

5.3.1.1 Reach 1 – Upstream of Storage

No impacts on the fish assemblages in Reach 1 are expected as a result of dam construction. Possible impacts may be associated with the construction of the relocated section of Salisbury Road, although it is unknown how far these works would extend into the region of Reach 1, which would not be inundated by the proposed storage.

5.3.1.2 Reach 2 – Storage

Sediments mobilised by the proposal could impact on fish at the dam construction site and further downstream. Fish could be affected by degraded habitat (outlined in Section 5.2.1.2) or directly by the suspended sediment. Susceptibility would vary among taxa. Australian smelt are relatively intolerant to elevated sediment loads and fish kills have been attributed to suspended sediment concentrations of 190 – 200 mg L^{-1} (Pusey *et al*. 2004). Habitat degradation caused by sedimentation is considered a threat to the status of catfish. Other species, such as the sea mullet, striped gudgeon and longfinned eel are tolerant of turbid waters. Fish are relatively mobile and have the capacity to seek out more favourable conditions and to recolonise following the disturbance. Any possible impact would depend on the magnitude and duration of the increase in sediment load.

5.3.1.3 Reach 3 – Dam wall to Glen Martin

The likelihood of an impact on fish in Reach 3 from elevated sediment loads mobilized by the Proposal is similar to that outlined in Section 5.4.1.2, and would decline with distance from the construction site or source of sediments.

5.3.1.4 Reach 4 – Glen Martin to Seaham Weir

Impacts on fish in Reach 4 from elevated sediment loads mobilized by works associated with the dam are less likely that Reach 3, and would decline with distance from the construction site or source of sediments. *Phragmites australis* and *Vallisneria* sp. beds are located in the Seaham Weir pool and can be an important habitat for juvenile bass migrating upstream from estuarine areas (Pusey *et al*. 2004). Although unlikely, significant damage to this habitat could result in an impact on bass recruitment.

5.3.2 Dam Filling Phase

5.3.2.1 Reach 1 – Upstream of Storage

There would be impacts on fish populations in Reach 1 during the filling of Tillegra Dam. The completed dam wall would create a near impassable barrier for fish migrating upstream (and often downstream). By preventing fish passage, the dam would cause the extirpation of most diadromous fish species that currently inhabit Reach 1.

There are likely to be 12 species of native fish within Reach 1. Twelve species of native fish were sampled in Williams River at experimental sites in Munni, at 120 mAHD (Table 2) (Brooks *et al*. 2004). Reach 1 begins just upstream at 150 mAHD therefore it is possible that this reach is within the upstream range of all 12 species. The Ecology Lab survey identified four fish species in Reach 1 (Table 2). Nine of the 12 species are definitely known to occur at altitudes greater than 150 mAHD and seven of these have been recorded from 600 m - 760 mAHD in other areas (Table 3).

Eight of these twelve species have a diadromous life history, meaning they migrate to estuarine habitats (Table 3), although the Cox's gudgeon can apparently complete its life cycle in freshwater (Pusey *et al*. 2004). Six of the eight are catadromous and must migrate to estuarine waters to spawn. Tillegra Dam would be a complete barrier to most migrating fish. Adults returning from estuarine or marine spawning grounds and/or juveniles from nursery areas, would not be able to return or recruit to Reach 1 populations. As such, these species would eventually become extirpated above the dam wall. Only Cox's gudgeon, short-finned eel and long-finned eel are known to climb barriers such as dam walls, although populations observed above dams can be smaller than those immediately below suggesting the barrier has had a negative impact on recruitment (Gehrke *et al. 2001*). This is particularly true for the Cox's gudgeon which has in some instances has been extirpated above dams and weirs, even though it may not be strictly amphidromous (Pusey *et al*. 2004). These three species are expected to persist in Reach 1 following the completion of the dam wall, albeit with diminished abundances. Other species likely to maintain viable populations in Reach 1 are potamodromous (or undefined) and include; the freshwater catfish, the flathead gudgeon, the dwarf flathead gudgeon, smelt and the introduced mosquitofish. The diadromous species expected to disappear from Reach 1 due to recruitment failure include sea mullet, freshwater mullet, striped gudgeon, freshwater herring and the Australian bass (Table 10). The disappearance of these species from Reach 1 represents the loss of 34 km of main stem habitat.

Decreases in recruitment to Reach 1 would be magnified for the two eels and Cox's gudgeon should the lower flows expected in Reaches 3 and 4 during the filling phase decrease fish passage at Seaham Weir (see Section 5.3.2.2 below). Although these three species, particularly the shortfinned and longfinned eels, would be least affected by changes to passage conditions at the Seaham Weir fishway.

For the non-diadromous species that persist in Reach 1, their once continuous populations would become fragmented by the dam barrier, and their ability to utilize habitat downstream (e.g. for foraging etc) would end. Some of these species are known to migrate or move large distances within river systems (Pusey *et al*. 2004). For example, smelt and flathead gudgeon have been observed to make facultative amphidromous and potamodromous migrations (Pusey *et al*. 2004). These movements are probably important as a dispersal mechanism for juveniles and sub-adults.

Once the storage begins to fill it is speculated that fish such as the long-finned eel and Cox's gudgeon which prefer lotic environments, and whose life history permits them to survive in an entirely freshwater system, may move upstream towards the faster moving water in Reach 1(Pusey *et al.* 2004).

5.3.2.2 Reach 2 – Storage

Reach 2 is expected to lose the same diadromous species as Reach 1 because of the barrier posed by the dam to upstream passage (Table 10). The loss of these species from Reach 2 represents an additional loss of 19 km of main stem habitat.

Reach 2 would transform from lotic to lentic during the filing phase. Only those species that can either climb the dam wall or are potamodromous/undefined, and can also inhabit lentic environments are expected to persist in the dam storage. Smelt, short finned eel, long finned eel, freshwater catfish, flathead gudgeon, dwarf flathead gudgeon and the introduced mosquitofish are all able to inhabit lentic environments and are often observed in lakes and dams (McDowall 1996, Pusey *et al*. 2004). Should the Cox's gudgeon persist in Reach 2 it would do so in much lower densities. Cox's gudgeon prefers faster flowing water, such as rapids, riffles and runs, which would cease to exist. A study in Lake Yarrunga, the storage above Tallowa Dam in NSW found Cox's gudgeon within the reservoir but in greatly reduced numbers (Gehrke *et al*. 2002). The other species may initially be found in reduced densities in the dam reservoir due to the lack of preferred microhabitat in the new and disturbed lentic environment of the Tillegra Dam storage.

Other introduced species not sampled within Reach 1 or 2 but known to thrive in disturbed lentic environments are goldfish and carp. These species are predicted to be present in the Williams River and should they currently inhabit Reach 2, or be introduced to the storage later, they would soon become established, and carp could eventually degrade available habitat and water quality.

Should the shift to lentic conditions facilitate algal blooms during the warmer months this may lead to fish kills within Reach 2 if severe.

5.3.2.3 Reach 3 – Dam Wall to Glen Martin

For a more detailed impact assessment of the proposed environmental flow strategy refer to the Environmental Flow and River Management Report.

The expected increase in frequency of low to moderate flows and the loss of high flows in Reach 3 during the filling phase may result in reduced water quality, fragmented fish populations and habitat, disruption of spawning cues and changes to fish passage past natural and artificial instream barriers.

The filling period may tend to favour those species that prefer stable low flows. Many potadromous species, such as smelt and flathead gudgeon, have peak spawning periods during the naturally low flow periods of spring so that larvae/juveniles have a greater chance of encountering invertebrate prey and are not swept downstream by larger flows (Pusey *et al*. 2004). Research has indicated that some native species are more tolerant to river regulation (Gehrke and Harris 2001). The introduced carp and mosquito fish prefer low flows and are tolerant to reduced water quality; therefore their abundance might be expected to increase during the filling phase. Some native species, such as striped gudgeon, longfinned eel and sea mullet are less sensitive to degraded water quality, such as reduced dissolved oxygen and increased nutrient concentration, and would not be as affected should water quality decline, unlike the more sensitive bullrout and Cox's gudgeon (Pusey *et al*. 2004).

It is expected that diadromous fishes migrating upstream (e.g. adults returning from spawning or new juvenile recruits) would mass at the base of the dam wall in an attempt to find a route past the barrier (Gehrke *et al.* 2001). Potamodromous species can also exhibit this behaviour, for example large aggregations of smelt and flathead gudgeon have been observed on the downstream side of barriers (Pusey *et al*. 2004). These fish may then experience increased mortality as predators exploit the aggregations or from density-dependent stresses.

The loss of moderate to large flows in the upper section of Reach 3 may cause a reduction in the availability of habitat used for foraging, spawning or shelter. Adult bass prefer deep pools and it is possible these may become less available, although declines in depth would have greater impact in shallow habitat. The predicted decline in riffle coverage and productivity would have the greatest effect on species which prefer this habitat such as Cox's gudgeon and smaller longfinned eels. Similarly, any loss of gravel beds within the upper range of 0.2 – 1.8 m during spring and summer may affect the spawning success and local recruitment of freshwater catfish. This species typically has a short home range and limited dispersal (relative to other fish) and is therefore more vulnerable to local habitat degradation.

Fish Passage

The environmental release strategy may affect the ability of fish to negotiate longitudinal passage in Reach 3 past potential natural barriers such as riffles, rockfalls and logjams or artificial barriers such as fishways and grading structures. Fish passage is limited by water depth and velocity, both of which are proportional to flow magnitude. A depth threshold represents the minimum flow required to generate sufficient depth for passage and a velocity threshold represents the maximum flow a fish can make headway into. The range of navigable flows therefore lies between these lower and upper limits. The size and timing of flow requirements for passage can vary among taxa, and for different size classes within taxa. Therefore changes to the flow regime can affect the capacity of fish to move up and downstream.

Most freshwater fish found in Reach 3 make longitudinal migrations up and/or down the river channel and require adequate flows to pass potential instream barriers (Table 11). Of the 15 species present in Reach 3, ten have a diadromous life history that requires them to migrate to estuarine habitats at some stage during their life cycle (Table 2). Seven of these species are catadromous and must migrate to estuarine or marine waters to spawn and three are amphidromous; their larvae are swept downstream to estuarine waters, and the juveniles later migrate back upstream into freshwater habitat. However it is possible that bullrout and Cox's gudgeon may be able to complete their life cycles in freshwater (Pusey *et al*. 2004).

Some of the non-diadromous species, such as smelt and flathead gudgeon, are known to make facultative potomadromous and amphidromous movements (Pusey *et al*. 2004). That is, they make opportunistic mass migrations within freshwater systems or sometimes into estuaries. These movements are not related to spawning but are probably dispersal mechanisms for juveniles and sub-adults, or made by fish recolonising upstream areas after being swept downstream by floodwaters. Although tagging studies of catfish have indicated adults are relatively sedentary and often do not move further than 50 m, barriers to movement are considered a possible threat to this species by some researchers (Morris *et al*. 2001, Pusey *et al*. 2004).

Fish Passage - Depth Thresholds

An understanding of the relative effects of depth on fish passage remains poor for the majority of Australian species. Adult bass have been observed to swim on their sides in depths as shallow as 5 cm for short periods and in experimental flume trials some adults (283 – 357 mm TL) could negotiate depths as low as 2.5 cm (Richardson 1984 in Pusey *et al*. 2004). However, for 100 per cent of adult bass to successfully navigate a reach, research indicates that depths of 20 cm are required (Richardson 1984 in Pusey *et al*. 2004). Other fish are capable of traversing much shallower water, particularly juveniles or adults of smaller species (Mitchell 1989, Koehn and O'Connor 1990, McDowall 1996, Langdon and Collins 2000, Baker 2003, Pusey *et al*. 2004). Three centimetres depth was needed to allow the passage of 100 per cent of small juvenile bass (27 – 38 mm TL) over short distances in experimental flume trials, although some individuals were able to cross depths of only 0.5 cm (Richardson 1984 in Pusey *et al*. 2004). Striped gudgeon, Cox's gudgeon, short-finned eel and long-finned eel are all able to move across wetted rocks, climb around rapids, and the latter three species can scale the vertical surfaces of weirs and dams (McDowall 1996, Langdon and Collins 2000, Gehrke *et al.* 2001, Pusey *et al*. 2004). However, this form of movement exposes fish to an increased risk of mortality from predation and physical stress. Adult bullrout, freshwater mullet and sea mullet, are far larger and deeper bodied than juvenile gudgeons or elvers/glass eels and would probably require deeper waters and hence larger flows for passage.

Fish Passage – Velocity Thresholds

Fish can sustain faster 'burst' speeds over short distances to overcome velocity barriers. Such 'burst' speeds cannot be maintained for long and fish must rest in between attempts. Lower velocities can be sustained for more prolonged swimming, such as might be required navigating longer runs. Studies that have investigated the maximum swimming abilities or the swimming behaviour of Australian or New Zealand (closely related) fishes include Mitchell (1989), Mallen-Cooper (1992, 1994), Langdon and Collins (2000), Baker (2003) and Nikora *et al.* (2003). Swimming velocities for prolonged and burst swimming are summarised in Table 12. Most of these studies (except for those on bass) were done in hydraulic flumes and as such the velocities represent fish swimming speed and not the ability of the fish to make headway into a flow of equivalent velocity. For species other than Australian bass, prolonged swimming velocities ranged from 0.28 m/s to 0.34 m/s, with most species close to 0.3 m/s (Table 12). Burst speeds for these species then ranged from 0.50 m/s (New Zealand smelt) to 1.6 m/s for sea mullet, and durations of burst speeds were reported to range from 2 to 30 seconds (Table 12). Research indicates that Australian bass have higher thresholds to flow velocity than most other fish species in the Williams River. Mallen-Cooper's (1992) study in a 1.5 – 1.8 m fishway found that 95 per cent of 40 mm (TL) bass (small juveniles) could pass through flows (i.e. make headway) of 1.02 m/s velocity and 95 per cent of 93 mm (TL) juveniles navigated 1.84 m/s flows. However another study found that only 50 per cent of adult bass (283 – 357 mm TL) successfully negotiated velocities of 1.85 m/s (Richardson 1984 in Pusey *et al*. 2004).

For the majority of species within the Williams River swimming speeds remain unknown. Many of the weaker swimmers, particularly small fish and diadromous juveniles, conduct upstream migrations during periods of relatively stable low flow (Table 11). Numerous researchers have recommended that flow velocities of less than or equal to 0.3 m/s in fishways are likely to facilitate the passage of all native species, and that velocities should not exceed 0.75 – 1.0 m/s, particularly for juvenile diadromous fish (30 – 80 mm TL) (Mallen-Cooper 1992, Harris and Mallen-Cooper 1994, Cotterell 1998, Langdon and Collins 2000). Mitchell (1989) suggested that a velocity greater than 1.5 m/s in fishways were likely to exclude all species except those that could cling or climb, and that velocities down to 0.5 m/s would become a species selective deterrent depending on the distance over which they were maintained. It is possible that fish within the Williams River can negotiate velocities close to these maxima as suggested by burst speeds listed in Table 12. Variable depths and roughness elements in natural riffles can also create low velocity pathways and rests that would facilitate passage.

The effect of the proposed environmental release regime on upstream fish passage along Reach 3 was assessed by estimating the change in the proportion of navigable flows during known migration season(s) (for details see Working Paper D 'Environmental Flows and River Management'). Navigable flows - or passage 'windows' - are the range of flows that lie above a depth threshold and below a velocity threshold (upper flow limit: see Section 4.3.1.3 below). Depth and velocity are both proportional to flow volume. Depth thresholds were taken from the literature where possible or estimated as equal to the body depth of the largest recorded individual. The 'burst' speeds listed in Table 12 were used as a guide to estimating velocity thresholds. Not all fish were assessed given the lack of information on the timing of migrations and swimming speeds, whilst others were assigned to the same velocity class as related species of a similar size and body shape. The juvenile/adult gudgeons (Eliotridae), *Anguilla* spp. elvers and smelt were classed as small weak swimming fish (0.8 m/s) with low depth requirements (0 – 3 cm). Juvenile bass and freshwater mullet were considered stronger swimming (1.0 m/s) small fish with low depth requirements (3cm), and adult bass and freshwater mullet were large strong swimmers (1.4 m/s) with deeper depth requirements (15 – 20 cm).

The effect of the filling regime on fish passage varied among fish classes, seasons, riffle types (broad low energy riffles; W8 and W9, or narrow channel high energy riffles; W7 and Glen Martin) and with distance downstream. The maximum velocities generated by the range of environmental releases at the upstream low energy riffle did not exceed the upper flow thresholds of any fish assessed; therefore passage is depth limited only. For fish with low depth requirements this represents a greatly expanded proportion of navigable flows relative to pre-dam flows, although this decreased downstream of the Chichester junction as additional inflows generated higher velocities.

For the weak-swimming small fish the potential increase in navigable flows was limited by a much smaller change to passage at the downstream 'bottleneck' high-energy riffle of Glen Martin. This is not the case for small, strong-swimming fish which should experience an improvement on an already significant passage 'window' at Glen Martin. This may increase upstream recruitment of these size classes. For large strong swimming adults, a gain in passage at Glen Martin due to an increase in the proportion of lower velocity flows would be offset by decreased passage at shallower low energy riffles further upstream.

The filling regime may result in the increase in the proportion of navigable flows at the Seaham Weir fishway, therefore potentially increasing the number of diadromous fish that recruit into Reach 3 (assuming that not all settle in Reach 4). A rise in the proportion of low to moderate flow events may increase the frequency of weir pool depths that cause low - negative head differentials, thereby inadvertently increasing passage at the otherwise ineffective submerged orifice fishway. However, this phenomenon would not assist those species which may have behavioural barriers to using a submerged orifice fishway, such as freshwater herring and the surface schooling sea mullet. Reduced freshwater outflows from the fishway may also make it harder for migrating fish to locate the submerged entrance. The filling phase would also cause a decline in flows that 'drown-out' the weir or cause the gates to be opened, which larger fish can occasionally negotiate during low head differentials.

Peak Flows

The significant loss of a range of moderate to large peak flows would lead to a decline in successful spawning and/or recruitment for some species.

Seasonal elevated flows can cue or facilitate the mass migrations of freshwater fish. Bass are cued by peak flows to begin downstream spawning migrations and migrating eels are often observed moving downstream during flood conditions (Pusey *et al*. 2004). During extended periods of low flow bass may delay their spawning migrations or not even reproduce at all (Pusey *et al*. 2004). Recruitment in NSW bass populations is proportional to the magnitude of discharge during the previous spawning season (Harris 1986). Growns and James (2005) found recreational catch of bass was positively associated with median flow volume and the number and duration of high flow events occurring in the previous year. High flow events cue adults to migrate, facilitate their downstream passage over depth barriers, and provide nutrients and organic matter to increase primary productivity in nursery areas (Pusey *et al*. 2004). It is expected that a significant loss of peak flows would cause a reduction in the spawning success and therefore recruitment of bass to Reach 3. The exact relationship between peak flows and recruitment of longfinned eels and shortfinned eels is unknown and is complicated by the extended marine phase of their life cycle.

The larvae/juveniles of amphidromous species, such as striped gudgeon, empire gudgeon (and potentially Cox's gudgeon) are swept downstream to productive nursery areas in estuaries. The relationship of flow volume to recruitment is unknown but it is possible that large peak flows in late summer and early autumn facilitate this downstream dispersal, particularly past reaches characterised by low flow velocity, such as the Seaham Weir pool. Empire gudgeons are also known to make upstream facultative mass migrations, involving juveniles, subadults and adults. Juvenile and sub-adult (15 – 25 mm TL) empire gudgeons have been observed aggregating below barriers after increases in flow suggesting that upstream dispersal is cued by elevated flows (Pusey *et al*. 2004). Flathead gudgeons also have a facultative mass dispersal phase. They have been observed massing below weirs following increases in flow (Pusey *et al*. 2004). It is unknown how important facultative migrations are to gudgeons, and whilst not related to spawning may allow the dispersal of juveniles and subadults.

The addition of one 2,000 ML/day flushing flow would not mitigate the impacts caused by the retention of peak events above 63 ML/day (i.e. the loss of the largest 70 per cent of peak flows at Tillegra). Ecological phenomena (such as bass recruitment) which are proportional to flow volume and/or frequency of peak events would continue to be impaired by the reduced flows of the environmental release strategy. Inputs from downstream sub-catchments would ensure that some semblance (although diminished in magnitude) of the historical pattern in peak flows is maintained, therefore fish populations further downstream Reach 3 would not affected to the same extent as those upstream of them.

Some effects of the filling phase environmental release strategy on the aquatic ecology of Reaches 3 would accumulate with time. The longer the dam takes to become operational (initiation of Run-of-River transfers) and reach FSL (commencement of spilling flows) the greater the potential for impairment of the biota of the Williams River.

5.3.2.4 Reach 4 – Glen Martin to Seaham Weir

The proportion of navigable flows within Reach 4 are not anticipated to change as there are few, if any, depth barriers to passage and the low gradient and wide channel produce lower velocity flows. Larger returning adult fish, especially sea mullet, may preferentially remain in the slower, deeper pools of Reach 4. The potential effect on fish recruitment into Reach 4 during dam filling are similar to those outlined in Section 5.3.2.3 with respect to passage at the Seaham Weir fishway and the reduction in the magnitude of peak flows.

The slower moving waters of Reach 4 are more likely to experience toxic algal blooms during periods of low flow which have been demonstrated to cause fish kills in other NSW coastal river systems.

Floods that overflow banks can be important to allow access of adult and/or juvenile fish to productive adjacent wetlands. The filling regime would be expected to reduce the frequency and magnitude of overbank flooding flows in Reach 4.

5.3.3 Dam Operational Phase

5.3.3.1 Reach 1 – Upstream of Storage

The impacts on fish in Reach 1 following the commencement of Run-of-River transfers are expected to be similar to the dam filling stage (Section 5.3.2.1). Depending on the time taken to fill the dam, short-lived diadromous species (other than the two eel species and the Cox's gudgeon) may have disappeared. Longer lived diadromous species would be composed of few individuals from older age classes.

5.3.3.2 Reach 2 – Storage

The impacts on fish in Reach 2 during dam operation are expected to be similar to the filling stage (Section 5.3.2.2). The development of riparian vegetation and macrophytes at the water level would provide improved habitat for the fish species that persist in the storage.

5.3.3.3 Reach 3 – Dam wall to Glen Martin

The increase in median discharges is predicted to be greatest during spring (and summer) due to the timing of Run-of-River transfers. This may affect those taxa adapted to a season that has been historically characterised by relatively stable low flows. The larvae/juveniles (and their prey) of fish spawning in freshwater reaches may be more likely to be swept downstream, particularly as Run-of-River transfers may reach 500 ML/day and last for 30 days. For non-diadromous fish this may reduce local recruitment in upstream areas and/or an increase in mortality as these fish are forced to take longer and more frequent dispersal migrations. Although high velocity flows in shallow gravel runs might disrupt catfish spawning they have an extended spawning season and would re-attempt following a return to lower flows.

Improved water and habitat quality would benefit the more sensitive fish species that may have been affected during the filling phase. An increase in riffle habitat availability and riffle fauna productivity may increase the abundance of fish species, such as Cox's gudgeon and small longfinned eel, which prefer this habitat and prey on associated macroinvertebrates. Conversely, these fish would lose habitat in upstream areas affected by scour where it is anticipated that riffle habitat would be lost. Similarly, the freshwater catfish may lose gravel nesting habitat.

Upstream Passage

The replacement of low to moderate flows with Run-of-River transfers would increase median velocities over most of the Reach 3 riffles, particularly during spring (and to a lesser extent summer) which is traditionally the period when most fish would attempt upstream migrations (Table 11).

For weak-swimming fish (upper limit 0.8 m/s) there is relatively little decrease in the historically small proportion of navigable flows at the high-energy riffles such as Glen Martin. Passage windows of these fish would decline more considerably at low-energy riffles as negotiable low - moderate flows are replaced with fresh-sized Run-of-River transfers that generate velocities above their thresholds, although one third to a half of all flows are predicted to be negotiable. Small strong-swimming fish would experience a slightly larger decline at both riffle types but would still have a larger proportion of navigable flows. The adult bass and freshwater mullet are predicted to suffer a dramatic decline in navigable flows at Glen Martin during winter. This would be because the Run-of-River transfers and spilling flows would generate velocities slightly in excess of the potentially conservative upper limit used for bass. Both the depth and the velocity threshold used for adult bass were conservative and it is likely that a number of individuals could still ascend beyond these limits.

The operational regime may reduce the proportion of diadromous fish recruiting upstream into Reach 3 due to declining passage at the Seaham Weir fishway. Flow data from 2002 demonstrated that seasonal low flow periods during spring (and to a lesser extent summer) resulted in the weir pool remaining below the preferred RL0.4 m – RL0.5 m management range for prolonged periods (Department of Commerce 2008). This inadvertently facilitates the upstream passage of diadromous juveniles through the fishway by increasing the period of low – negative head differential during the migration season. The predicted increase in spring flow volume due to the calling of Run-of-River transfers would potentially decrease the number of days that the weir pool falls below RL0.4 m, and as such may decrease the amount of time during spring and summer when small fish can navigate the fishway.

Peak flows

The increase in frequency, magnitude and duration of peak flows relative to the filling phase would benefit those species that require seasonal peak flows to cue and/or facilitate spawning or dispersal migrations. However, the predicted magnitude of peak flows is consistently lower than historical flows for much of the peak distribution. This may therefore negatively affect ecological processes that are proportional to flow magnitude, such as bass recruitment. Therefore, the recruitment of species such as Australian bass would remain at lower levels than had the dam not been built. These patterns may be similar for other species, although the exact nature of the relationship with peaks flows to recruitment in unknown.

5.3.3.4 Reach 4 – Glen Martin to Seaham Weir

The potential impacts on fish in Reach 4 during dam operation are similar to those outlined in Section 5.3.2.3 with respect to passage at the Seaham Weir fishway and the reduction in the magnitude of peak flows. The proportion of navigable flows within Reach 4 are not anticipated to change as there are few, if any, depth barriers to passage and the low gradient and wide channel produce lower velocity flows.

The increased flushing ability of the peak flows would help to improve water quality in the weir pool relative to the filling phase.

5.4 Impacts on Aquatic Macroinvertebrates

5.4.1 Construction Phase

5.4.1.1 Reach 1 – Upstream of Storage

No impacts in Reach 1 on aquatic macroinvertebrates are expected as a result of dam construction. There may be possible impacts arising from the construction of the relocated section of Salisbury Road although it is unlikely (but unknown) how far these works may extend into the region of Reach 1, which would not be inundated by the proposed storage.

5.4.1.2 Reach 2 – Storage

Given the impacts on Reach 2 aquatic habitat from construction outlined in Section 5.2.1.2, it is possible there would be localized impacts on aquatic macroinvertebrates in the same locations. Increased levels of suspended sediments could clog the gills and/or feeding apparatus of certain macroinvertebrates, such as the mayfly (Leptophlebidae) and the less abundant stonefly (Gripopterygidae), both of which have external gills and are sensitive to reduced water quality (Signal grades = 8) (Waters 1995). Additionally, increases in turbidity and suspended sediments would reduce primary productivity of plant material and, as a result, negatively affect algal grazers and those that feed on periphyton (Ryan 1991). This includes the abundant species of mayflies (Ameletopsidae and Baetidae, Signal grades 7 and 5 respectively), caddisflies (Philopotamidae and Leptoceridae, Signal grades 8 and 6 respectively), and beetles (Elmidae and Psephenidae, Signal grades 7 and 6 respectively).

As has been the case in areas around Salisbury, local habitat degradation can lead to the replacement of sensitive taxa with more tolerant taxa (Chessman and Growns 1994). Often in disturbed sites the assemblage is characterized by a lower diversity of abundant, tolerant taxa. However, the impacts from mobilized sediment would depend on the magnitude and duration of the disturbance, the sensitivity of the organisms present (Band A at Site W6 near the proposed dam wall), and their ability to seek out favourable conditions elsewhere and recolonise following the disturbance. In this instance it is may be possible for macroinvertebrates to recolonise the lotic habitat following possible sediment mobilization but this would only be temporary given the reach would be inundated after construction works are completed.

5.4.1.3 Reach 3 – Dam wall to Glen Martin

As for Section 5.4.1.2. The likelihood and/or magnitude of impacts on macroinvertebrates would be greater closer to the construction site at the dam wall where turbidity and sedimentation are the highest. High levels of suspended sediments are known to increase macroinvertebrate drift rates (Rosenberg and Weins 1975) and reduce populations of bottom dwelling invertebrates (Ryan 1991). This could be attributed to the direct smothering effects that the particulates have on individuals with high oxygen requirements and external gills (Waters 1995) as well as sediment deposition that results in the smothering of periphyton food sources (Yamada and Nakamura 2002) and reduction of available habitat as interstitial spaces on the stream bed are filled (Ryan 1991). Pollution intolerant taxa such as Ameletopsidae, Elmidae, Leptophlebiidae, Leptoceridae, Philopotamidae and Psephenidae were abundant at Site W7, closest to the proposed dam wall and construction site, and are more likely to be affected by the lower water quality and habitat reduction caused by increased sediment loads.

5.4.1.4 Reach 4 – Glen Martin to Seaham Weir

As for Section 5.4.1.2 but as this reach is much further downstream, macroinvertebrate assemblages are less likely to be impacted by increased sediment loads which would settle out further upstream.

5.4.2 Dam Filling Phase

5.4.2.1 Reach 1 – Upstream of Storage

As the dam gradually fills, it is speculated that fish preferring lotic environments and whose life history permits them to survive in an entirely freshwater system would move upstream towards the faster moving water in Reach 1. All of these species mentioned in Section 5.3.2.1 have diets that rely heavily on macroinvertebrates (Pusey *et al.* 2004) and their increased abundance in Reach 1 would impose higher predation pressures on the populations of macroinvertebrates found there.

Should carp become established in the dam and colonize Reach 1 there is a possibility that habitat degradation could lead to an increase in pollution tolerant macroinvertebrate taxa. Although other research described macroinvertebrate assemblages in the Salisbury area as significantly impaired our investigations found sites in Reach 1 similar to reference condition (Band A) at the time of sampling.

5.4.2.2 Reach 2 – Storage

The inundation of Reach 2 would initially involve the loss of much of aquatic macroinvertebrate fauna associated with lotic habitat, especially those taxa requiring high levels of oxygen that are specific to riffles and high energy flows. Some of the more dominant taxa within Reach 2 (W3-W6) that would be negatively affected are the mayflies (Ameletopsidae and Leptophlebiidae, Signal grade 7 and 8 respectively), true flies (Athericidae, Signal grade 8), toebiters (Corydalidae, Signal grade 7), beetles (Elmidae and Psephenidae, Signal grade 7 and 6 respectively), stoneflies (Gripopterygiidae, Signal grade 8), and caddisflies (Helicopsychidae, Hydropsycidae, Leptoceridae, and Philopotamidae, Signal grade 8, 6, 6, and 8 respectively). The extent of the loss of macroinvertebrates would depend on the rate at which the dam fills. All sites sampled in Reach 2 (W3 – W6) were considered equivalent to reference streams (Band A). However, lakes with rivers flowing into them do share some river fauna, such as those found in pool edge habitat. Over time it is possible a different assemblage would establish itself in the reservoir, one adapted to lacustrine environments (e.g. lakes).

Given the potential for eutrophication in the reservoir the assemblage could resemble the severely impaired assemblages that have been observed in the Seaham Weir pool.

5.4.2.3 Reach 3 – Dam wall to Glen Martin

The predicted reduction in the wetted width of the channel would result in an overall decline of the productivity of shallow habitat such as riffles and gravel/sand bars and the abundance of associated taxa, such as Philototamid caddisflies and water pennies (Psephenidae) (Appendix 10). Some taxa, such as adult freshwater mussels (Hyriidae) are adapted to prolonged dry periods and bury themselves in sediment and seal their shells (Gooderham and Tsyrlin 2002).

The diversity and abundance of sensitive macroinvertebrate species may decline in areas where habitat and/or water quality declines, such as a reduction in dissolved oxygen and increases in nutrients and algal activity. As assemblages became increasingly impaired they would be dominated by relative few (but abundant) pollution tolerant taxa. AusRivAS assessments made in this survey indicated that macroinvertebrates communities had been significantly impaired at some Reach 3 riffles and pools, although these results were likely affected by the elevated flows during sampling (Table 8). Other studies have indicated that sensitive taxa are well represented (Chessman and Growns 1994, Web Reference 5). Sensitive taxa relatively common in Reach 3 during this survey included beetles (Elmidae and Psephenidae, Signal grades 7 and 6), caddisflies (Leptoceridae, Hydropsychidae and Philoptamidae, Signal grades 6, 6 and 8) and the mayfly (Leptophlebiidae, Signal grade 8)(Appendix 10). Chessman and Growns (1994) found pool rock macroinvertebrate assemblages downstream of Chichester Dam quite different to those in equivalent unregulated habitat, with a reduction in sensitive mayfly and caddisfly species and increase in water snails and silt-tolerant mayflys. Pollution tolerant taxa relatively common to Reach 3 that might be expected to increase in abundance include the introduced water snail (Physidae, Signal grade 1), freshwater shrimp (Atyidae, Signal grade 3), waterboatmen (Corixidae, Signal grade 2), segmented worm (Oligochaeta, Signal grade 2) and water striders (Veliidae, Signal grade 3).

A regime dominated by less variable low to moderate flows may benefit fauna that are reliant on seasonal periods of stable low flow and those more tolerant of lentic conditions. For example, planktonic larvae are less likely to get swept downstream potentially increasing survival and local recruitment and many pool edge taxa prefer low velocity flow conditions.

Not enough is known about flow thresholds to be certain that the environmental release strategy would capture or mimic enough flow volume or temporal variability for taxa with specific requirements. Species needing higher flow, such as passive filter feeders may experience local declines in abundance or distribution, but it may be that the peaks contained within the translucent flows are sufficient to cue those species that require seasonal peaks to synchronously spawn or emerge from an aquatic larval stage (e.g. *C. novaehollandiae*). Potential impacts on macroinvertebrates should diminish downstream as flows would tend back to historical patterns with the inputs form Chichester Dam and other tributaries.

The larvae of some macroinvertebrates drift downstream (e.g. stoneflies and mayflies). The adults fly upstream to lay their eggs, counteracting this drift and ensuring the populations maintain their distribution. The dam wall and lentic storage would be barriers to this downward drift. As such it is possible some taxa may not recruit via drift into lotic habitats directly underneath the dam wall.

Additionally, as is discussed in Section 5.3.2.3, large aggregations of diadromous and potamodromous fish are expected to accumulate at the base of the dam wall. Many of these fish have diets that rely heavily on macroinvertebrates (Pusey *et al.* 2004) and their increased numbers in Reach 3 would impart higher predation pressures on the macroinvertebrate communities that are present.

5.4.2.4 Reach 4 – Glen Martin to Seaham Weir

There is little shallow riffle habitat in this reach and therefore wetted width is not expected to decline as much as Reach 3. The low gradient Reach 4 is currently characterised by lower velocity flows, lower water quality and pool edge macroinvertebrate fauna that are severely impaired (Web Reference 5). Macroinvertebrate fauna sampled during 1997 in pool edge habitat near Clarence Town included beetles (Hydrophilidae, Signal grade 2), introduced water snail (Physidae and Planorbidae, Signal grade 1 and 2), freshwater shrimp (Atyidae, Signal grade 3), waterboatmen (Corixidae, Signal grade 2), water striders (Veliidae, Signal grade 3) and water slaters (Sphaeromatidae, Signal grade 1)(Web Reference5). The pool edge assemblage was given as AusRivAS assessment of Band C (severely impaired). If water quality and habitat decline further during the filling phase it is possible for the macroinvertebrate communities to become further degraded. The lowest possible AusRivAS assessment is Band D (extremely impaired).

5.4.3 Dam Operational Phase

5.4.3.1 Reach 1 – Upstream of Storage

Impacts in Reach 1 during the operational phase are considered similar to those outlined in Section 5.4.2.1.

5.4.3.2 Reach 2 – Storage

It is expected the macroinvertebrate assemblage in the storage would further its transition to that expected of a river-fed lake. Predator taxa such as dragonflies, bugs, and beetles should become established (Gooderham and Tsyrlin 2002). This may depend on the degree of ongoing disturbance in the reservoir, such as eutrophication, establishment of weed species or the use for recreation (e.g. impact of boat wash on edge habitat and communities and clearings for human access).

5.4.3.3 Reach 3 – Dam wall to Glen Martin

The improvement of water and habitat quality in Reach 3 may allow pollution sensitive taxa to return to their historical ranges of distribution and abundance. The predicted increase in the availability of riffle habitat and gravel/sand beds may result in an overall increase in the abundance of associated macroinvertebrate fauna. In the upper sections of Reach 3 an increase in productivity may be offset by scour of bed materials, leaving bedrock and large boulders. Bedrock is relatively featureless, and would not support the same assemblages as the lost habitat forms.

It is possible that an increase in sheer stress associated with higher riffle velocities may select against benthic organisms less tolerant of higher velocity flows. Macroinvertebrate assemblages have changed downstream of hydroelectric dams that make high velocity releases for power generation (Bunn and Arthington 2002). Although deep pools can be a velocity refuge during high volume flows, pool edge fauna with life history traits that require seasonal low flows (i.e. planktonic larvae) may be affected by the larger Run-of-River transfers (~ 500 ML/day). Run-of-River transfers of this magnitude would generate 30-day duration flows with velocities of ~ 0.25 m/s at intermediate pools (W7: median depth 1.63 m) increasing to ~0.43 m/s at shallow pools (W9: median depth 0.52 m) (Connell Wagner unpublished data). The freshwater mussel, *C. novaehollandiae,* retains its glochidia over winter and then releases them in spring to find fish hosts. It is unknown what effect an increase in spring flows might have on the capacity of the glochidia to find a host fish.

5.4.3.4 Reach 4 – Glen Martin to Seaham Weir

The erosive potential of bulk transfers should diminish in the wider channel of Reach 4 and the Seaham Weir pool, and so scour is anticipated to occur.

Impacts associated with poor water quality may decrease if the bulk releases achieve some flushing function during the summer months, when the reach is prone to problems, such as eutrophication.

5.5 Impacts on Threatened and Protected Species

There are no listed threatened or protected fish or aquatic macroinvertebrates within the study area.

The following table summarises impacts on river habitats, biota and water quality in Reaches 1 to 4 of the Williams River.

Table 13: Summary of impacts on aquatic habitats, biota and water quality in reaches in the Williams River predicted due to the construction, filling and operation of Tillegra Dam.

Reach	Receptor	Phase		
		Construction	Filling	Operation
Reach 1: Upstream of storage	River Habitat	Potential sedimentation due to road works	None/minor	None/minor
	Biota	None/minor	Reduction in diversity and abundance of fish due to blocked fish passage Flow-on effects on macroinvertebrate prey species	Reduction in diversity and abundance of fish due to blocked fish passage Flow-on effects on macroinvertebrate prey species
	Water Quality	Potential increased turbidity	None/minor	None/minor
Reach 2: Storage	River habitat	Potential sedimentation Damage to riparian vegetation	Incremental change to lentic habitat	Loss of 19 km of lotic habitat, significant change to lentic habitat. Bank erosion from wind waves/recreational uses
	Biota	Potential reduction in abundance of fish and macroinvertebrates species susceptible to elevated/variable sediment loads	Reduction in diversity and abundance of fish due to blocked fish passage Favourable conditions for proliferation of introduced pest species Reduction in diversity and abundance of macroinvertebrates	Reduction in diversity and abundance of fish due to blocked fish passage Incremental shift to assemblages of fish and macroinvertebrates typical of lentic habitats Favourable conditions for proliferation of introduced pest species
	Water Quality	Elevated/variable turbidity	Potential concentration of nutrients, algal blooms	Ongoing potential for algal blooms. Stratification of storage.

Table 13 Continued.

Reach 3: Dam wall to Glen Martin	River habitat	Sediment mobilisation	Potential fragmentation, degradation, fine sediment accumulation, decrease in extent riffle, gravel/sand bar habitats, wetted width, expansion of channel by macrophytes: magnitude depends on EF	Sediment scouring, riffle mobilisation, bank erosion gradual sediment starvation in upper Reach 3 magnitude depends on nature of EF Increase in channel wetted width and associated habitat features
	Biota	Potential reduction in abundance of fish and macroinvertebrates species susceptible to elevated/variable sediment loads	Changes in fish assemblage due to: alteration to patterns of longitudinal passage and reduction in spawning and foraging habitat, spawning cues, upstream migration cues, peak flows and food. Possible increased fish passage at Seaham Weir Fishway Reduction in invertebrate diversity and abundance due to changes in water quality and localized accumulation of fine sediments	Changes in fish assemblage due to: alteration to patterns in upstream passage and changes to fish spawning and foraging habitat, reduction in magnitude of peak flows. Possible decreased fish passage at Seaham Weir fishway. Reduction in macroinvertebrate diversity and abundance due to: downstream drift without replenishment, increased bed sheer stresses
	Water Quality	Increased turbidity	Possible stagnation, concentration of nutrients in remaining pools: magnitude depends on EF	Increased variability in turbidity: magnitude depends on nature of EF
Reach 4: Glen Martin to Seaham Weir	River Habitat	None/minor	Potential decrease in wetted width: reduced flooding of wetland habitat: magnitude depends on EF	Increased bank erosion and slumping, magnitude depends on EF
	Biota	None/minor	Changes in fish assemblage due to: reduction in magnitude and frequency of peak flows that cue/facilitate migration and lateral passage. Possible increase in passage at Seaham Weir fishway. Reduction in invertebrate diversity and abundance due to reduced water quality	Changes in fish assemblage due to: reduction in magnitude of downstream peak flows that facilitate migration and lateral passage. Possible decreased fish passage at Seaham Weir fishway. Reduction in invertebrate diversity and abundance due to reduced water quality
	Water Quality	None/minor	Potential concentration of nutrients, potential algal blooms: magnitude depends on EF	Increased variability in suspended sediments/turbidity, magnitude depends on EF

6.0 RECOMMENDATIONS

6.1 Mitigation of Impacts

6.1.1 Sediment Control

The mobilisation of sediment into Williams River and its tributaries can be minimised through the use of standard sediment and erosion control procedures during construction of the dam and the relocated section of Salisbury Road.

Erosion and sediment controls should be installed prior to any construction or earthworks, including bunding, silt fences, silt curtains, drains and settlement ponds. Where possible, works should not take place within 50 m of any watercourse, and disturbed areas or spoil should be cleared up and/or revegetated following the completion of construction.

6.1.2 Environmental Flows

Low base flows and smaller peak flows would be protected by the proposed '90/30' environmental release strategy during both the filling and operational phases. Impacts may arise during the filling phase from the loss of larger base and peak flows for ecological processes related to magnitude and frequency of peak flows. Similarly, the predicted distribution of Run-of-River transfers would create changes to the natural flow regime in Reach 3 and 4 and may affect those species with seasonal flow requirements.

It is recommended that:

- multiple larger peak flow events (e.g. freshes) be released each year during the filling phase;
- the timing and relative frequency of additional fresh event releases should mimic any pattern and seasonality in the historical flow distribution;
- Run-of-River transfers should commence prior to the dam reaching FSL. Run-of-River transfers could be used to replace some added fresh event releases on a one-for-one basis;
- the temporal variability and profile of all environmental flows should occur within the expected limits of equivalent historical flows. For example; within the base case scenario, the proposed Run-of-River transfers would have a daily volume that is constant for approximately 30 days. The same total volume could be transferred with a more natural profile, such as; a shorter event duration (e.g. 10 days), a higher initial peak and a decaying tail. Similarly, environmental releases should not be made on the basis of demand or price for electricity generated in the hydroelectric plant (which might generate erratic or diurnal flow patterns) and the rate of rise and fall of releases should remain within natural limits;
- changes be made to the current protocols governing the calling of Run-of-River transfers so that the predicted seasonal flow distribution during dam operation mimics that of the historical period (i.e. to mitigate the current prediction of a disproportionate allocation of Run-of-River transfers to spring and summer);
- should the storage fall below FSL the additional peak event releases are re-initiated until the storage reaches FSL and the potential for spilling resumes;

- adequate flows are allocated to the proposed fish lift at Tillegra Dam and upgraded fishway at Seaham Weir;
- increase the minimum number of event releases (additional fresh events and Run-of-River transfers) during the filling phase as the time taken to reach FSL increases to reduce possible accumulating impacts of the filling phase release regime (e.g. see Table 14 below).

Table 14. An example frequency distribution of event releases during the filling phase

Year Since Dam Filling Began	Number of Fresh Releases (FR)	Number of Run-of-River Transfers (ROR)	Minimum Number of Event Releases	Example Distribution of FRs and RORs by Season			
				Sprin g	Summer	Autumn	Winter
0	6	0	6		1 FR	3 FR	2 FR
1	6	0	6		1 FR	3 FR	2 FR
2	6	0	6		1 FR	3 FR	2 FR
3	5	1	6		1 ROR	3 FR	2 FR
4	5	1	6		1 ROR	3 FR	2 FR
5	5	2	7	1 FR	1 ROR	2 FR + 1 ROR	2 FR
6	5	3	8	1 FR	1 FR + 1 ROR	2 FR + 1 ROR	1 FR + 1 ROR
7	5	3	8	1 FR	1 FR + 1 ROR	2 FR + 1 ROR	1 FR + 1 ROR
8	5	3	8	1 FR	1 FR + 1 ROR	2 FR + 1 ROR	1 FR + 1 ROR
9	5	3	8	1 FR	1 FR + 1 ROR	2 FR + 1 ROR	1 FR + 1 ROR
10	5	4	9	1 FR	1 FR + 1 ROR	2 FR + 2 ROR	1 FR + 1 ROR
11	5	4	9	1 FR	1 FR + 1 ROR	2 FR + 2 ROR	1 FR + 1 ROR
12	5	4	9	1 FR	1 FR + 1 ROR	1 FR + 2 ROR	2 FR + 1 ROR
13	5	4	9	1 FR	1 FR + 1 ROR	2 FR + 2 ROR	1 FR + 1 ROR

Whilst the addition of some flow events during the filling phase may not ameliorate impacts of processes related to flow volume and/or frequency of peak events, such as the recruitment of bass or the availability of riffle habitat, it may benefit taxa with life histories/behaviour cued by seasonal elevated flows and restore physical processes such as macrophyte disruption and the flushing of fines. Similarly, the maintenance of natural temporal patterns in flow would facilitate seasonal flow-dependent events such as the upstream migration of juvenile diadromous fish.

6.1.3 Fishways

It is recommended that a fishway be constructed to maintain linkages between fish populations and allow fish passage past Tillegra Dam (upstream and downstream) between Reaches 1/2 and Reaches 3-5. Since the dam wall would be 76 m a high fishway or fish lift design would be required. Fishways on high dams are rare in Australia although they have been shown to be successful overseas on dam structures as high as 100 m (Gehrke *et al.* 2001). Migrating fish are attracted to a trap on the fish lift using a water outflow and are then transported up the dam wall to the reservoir and released. High fishways are relatively untested on native Australian fish species and would be a major capital works program involving considerable expense. NSW Department of Commerce (2008) outlined a draft proposal for a fish lift at Tillegra Dam for upstream passage. To achieve downstream fish passage from the storage there two options have been outlined, either; (i) a fish lock system incorporated into the intake tower (ii) an overflow gate and dedicated fish discharge channel integrated into the spillway (Department of Commerce 2008). The attraction system for upstream passage would require a dedicated continuous flow of 20 ML/day.

To mitigate potential impacts on fish passage at the Seaham Weir fishway from the proposed Tillegra environmental flow release strategy (See Section 6 below) the existing submerged orifice fishway should be replaced with a structure(s) that operates over a much wider range of flows and allows the passage of smaller, weaker fish and macroinvertebrates which are more common in Australian freshwater systems (particularly diadromous juveniles). NSW Department of Commerce (2008) has outlined several options for upgrading the Seaham Weir fishway, favouring a single exit ungated vertical slot fishway. Vertical slot fishways facilitate passage for a greater abundance and diversity of Australian fish than salmonid fishways (Stuart and Mallen-Cooper 1999, Stuart and Berghuis 2002, Stuart *et al*. 2008a). Current designs have shallow slopes (1:32 or 3.1 per cent), creating a small differential head between each pool (~0.05 – 0.1 m) which generates lower maximum velocities (1.4 m/s) and turbulence (~4.2 Wm^{-3}). Although vertical slot designs allow passage for much smaller fish than salmonid fishways they can still represent a barrier to very small fish (e.g. < 30-40 mm TL). This can be a problem at tidal weirs where small juvenile diadromous fish attempt upstream migrations. Research is continuing into designs that would improve passage of small fish, including gated vertical slot fishways, fish locks and low slope narrow denil fishways (Mallen-Cooper and Stuart 2007, Stuart *et al*. 2008b). The latter are dedicated purely to passage of small fish and are to be used in conjunction with other fishways that benefit larger species.

6.1.4 Replenishment of Scoured Bed Material

The mobilization of bed material in Reach 3 by sediment-poor discharges would lead to the loss of riffle habitat and sand/gravel bars and would expose the underlying bedrock. In order to maintain invertebrate and fish communities associated with these habitat forms a replenishment program with appropriate size classes of particles should be initiated when and where they are needed.

6.1.5 Monitoring

A monitoring program should be implemented to examine potential effects the environmental release strategy could have on aquatic biota and to demonstrate the efficacy of mitigation measures designed to reduce impacts from the construction and operation of Tillegra Dam. Specific ecosystem components to be measured should include:

- The passage of fish upstream via the Tillegra fish lift and upgraded Seaham Weir fishway. This should be monitored for a range of flow conditions, a number of fish species and size classes, with emphasis on small juvenile life stages.
- Macroinvertebrate assemblages in riffle and pool edge habitats within reaches 3 and 4. Changes in macroinvertebrates assemblages would indicate the effect of encroachment into the river at different distances down the river. Focus should be on reaches nearest the dam wall and monitoring should begin before construction commences. Monitoring techniques should include quantitative methods and AusRivAS and monitoring should be at least twice within the Autumn and Spring AusRivAS sampling periods (March 15 to June 15 and September 15 to December 15, respectively). .

- Fish assemblages from Reach 1 to 4. Methods should target juveniles or young-of-the year of key species, such as Australian bass, and should focus on reaches 3 and 4. Monitoring should begin during filling phase. Adult populations could be also be monitored in reaches 3 and 4 in conjunction with the study of upstream passage through Seaham Weir. Monitoring catches from recreational anglers could also be done to examine changes in adult populations of bass.
- Macrophyte communities should be monitored as indications of terrestrial encroachment into the river.

6.2 Lake Habitat

Vegetation in the inundated area should be left in place to provide habitat for fish. These standing snags would provide habitat for surviving or stocked native species.

Stocking of Tillegra storage with Australian bass is a possible management option as it is a popular fish targeted by recreational fishers. Stocking of bass for the purpose of supporting a recreational fishery has been successful in other NSW artificial impoundments, such as Tallowa Dam (Gehrke *et al*. 2002). However, the future level of recreational use of the storage is yet to be determined and during the filling period public access would be restricted for health and safety reasons. Stocking is a form of compensation for the impact of dams on fish communities but it does not mitigate the cause of the population decline, or the permanent loss of lentic habitat. Continued stocking of all the affected species in Reach 2 is not technically possible and too costly (Marsden *et al*. 1997 in Gehrke *et al*. 2002). Gehrke *et al*. (2002) found that stocking in Lake Yarrunga had little effect in rehabilitating fish communities upstream of the storage (i.e. such as the fish assemblage in Reach 1 which would also lose most diadromous species).

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TABLES

Table 1. Species of fish that have been recorded in the region of the study area or whose published distribution includes the study area. # = alien species, s = sampled, d = published distribution includes the study area (Reaches 1 to 4). [a] = Species not sampled or predicted to occur in the study area by McDowall (1996) but NSW DPI lists the Hunter River Catchment as within the carp's distribution. b = Catfish populations in the Hunter River Catchment may be translocated Western drainage species.

Scientific Name	Common Name	The Ecology Lab 2007	Bionet	Gehrke *et al*. 1997	Brooks *et al*. 2004	McDowall 1996
Anguilla australis	Shortfinned eel		s		s	d
Anguilla reinhardtii	Longfinned eel	s	s		s	d
Potamalosa richmondia	Freshwater herring		s	s	s	d
Chanos chanos	Milkfish					d
Gambusia holbrooki	Gambusia#	s	s		s	d
Antherinosoma microstoma	Smallmouthed hardyhead					d
Psuedomugil signifer	Pacific blue-eye					d
Ambassis marianus	Estuary glassfish					d
Carassius auratus	Goldfish#					d
Cyprinus carpio	Carp#[a]					
Elops hawaiensis	Giant herring		s			
Liza argenta	Flat-tail mullet					d
Mugil cephalus	Sea mullet		s	s	s	d
Myxus elongatus	Sand mullet					d
Myxus petardi	Freshwater mullet		s	s	s	d
Valamugil georgii	Fantail mullet					d
Galaxias brevipinnis	Climbing galaxias		s			
Galaxias maculatus	Common jollytail					d
Galaxias olidus	Mountain galaxias					d
Retropinna semoni	Australian smelt	s	s	s	s	d
Gobiomorphus australis	Striped gudgeon	s	s	s	s	d
Gobiomorphus coxii	Cox's gudgeon	s	s	s	s	d
Hypseleotris compressa	Empire gudgeon		s			d
Hypseleotris galii	Fire-tailed gudgeon					d
Hypseleotris sp.	Unidentified gudgeon		s			
Philypnodon grandiceps	Flathead gudgeon	s	s	s	s	d
Philypnodon sp.	Dwarf flathead gudgeon		s	s	s	d
Psuedogobius sp. 9	Blue spot goby					d
Afurcagobius tamarensis	Tamar River goby					d
Amoya bifrenatus	Bridled goby					d
Redigobius macrostoma	Largemouth goby					d
Macquaria novemaculeata	Australian bass		s	s	s	d
Macquaria colonorum	Estuary perch					d
Notesthes robusta	Bullrout		s	s		d
Tandanus tandanus	Freshwater catfish[b]		s	s	s	d

Table 2. Species of fish that have been sampled in the study area by reach. # = alien species. ✓ = Species present in survey, ns = no sampling took place in this reach.

Scientific Name	Common Name	Reach 1: Upstream of inundation area		Reach 2: Inundation area			Reach 3: Dam wall to Glen Martin						Reach 4: Glen Martin to Seaham Weir		Life History
							Dam wall to Chichester River confluence		Chichester River confluece to Dungog		Dungog to Glen Martin				
		Bionet	TEL 2007	Bionet	Brooks *et al* . 2004	TEL 2007	Bionet	TEL 2007	Bionet	TEL 2007	Bionet	TEL 2007	Bionet	TEL 2007	
Anguilla australis	Shortfinned eel			✓	✓							ns		ns	Catadromous
Anguilla reinhardtii	Longfinned eel		✓	✓	✓	✓	✓	✓	✓	✓	✓	ns		ns	Catadromous
Potamalosa richmondia	Freshwater herring			✓	✓				✓		✓	ns		ns	Catadromous
Gambusia holbrooki	Gambusia#			✓	✓		✓			✓		ns		ns	Potamodromous
Elops hawaiensis	Giant herring	✓										ns		ns	Amphidromous
Mugil cephalus	Sea mullet			✓	✓						✓	ns		ns	Catadromous
Myxus petardi	Freshwater mullet			✓	✓				✓		✓	ns		ns	Catadromous
Retropinna semoni	Australian smelt		✓	✓	✓	✓	✓	✓	✓	✓	✓	ns		ns	Potamodromous
Gobiomorphus australis	Striped gudgeon			✓	✓	✓	✓	✓			✓	ns		ns	Amphidromous
Gobiomorphus coxii	Cox's gudgeon		✓	✓	✓	✓	✓	✓	✓	✓	✓	ns		ns	Amphidromous/Potamodromous
Hypseleotris compressa	Empire gudgeon								✓		✓	ns		ns	Amphidromous
Hypseleotris sp.	Unidentified gudgeon			✓			✓					ns		ns	Amphidromous
Philypnodon grandiceps	Flathead gudgeon		✓	✓	✓						✓	ns		ns	Undefined
Philypnodon sp.	Dwarf flathead gudgeon			✓	✓		✓		✓		✓	ns		ns	Undefined
Macquaria novemaculeata	Australian bass			✓	✓		✓		✓		✓	ns	✓	ns	Catadromous
Notesthes robusta	Bullrout										✓	ns		ns	Catadromous/Potadromous
Tandanus tandanus	Freshwater catfish			✓	✓		✓		✓		✓	ns		ns	Potamodromous

Table 3. Life History and habitat attributes of some species found in the Williams River, Reaches 1 to 4. Data sources: McDowall 1996, Pusey *et al* . 2004. Note: majority of data from surveys in south east Queensland.

Scientific Name	Common Name	Maxiumum Recorded Altitude (mAHD)	Water velocity of habitat (m s^{-1})			Water depth of habitat (m)		
			Minimum	Mean	Maxiumum	Minimum	Mean	Maximum
Anguilla australis	Shortfinned eel	180	0	0.14	0.55	0.10	0.42	1.05
Anguilla reinhardtii	Longfinned eel	790	0	0.16	0.87	0.06	0.39	1.05
Retropinna semoni	Australian smelt	760	0	0.19	0.87	0.05	0.37	0.04
Gobiomorphus australis	Striped gudgeon	160	0	0.10	0.87	0.10	0.44	1.10
Gobiomorphus coxii	Cox's gudgeon	700	0	0.18	0.55	0.13	0.34	0.74
Hypseleotris compressa	Empire gudgeon	60	0	0.12	0.85	0.10	0.46	1.19
Philypnodon grandiceps	Flathead gudgeon	700	0	0.10	0.87	0.10	0.47	1.08
Philypnodon sp.	Dwarf flathead gudgeon	700	0	0.08	0.71	0.07	0.43	1.08
Macquaria novemaculeata	Australian bass	600	-	<0.10	-	0.30	>2.00	-
Notesthes robusta	Bullrout	100	0	0.16	0.55	0.22	0.58	1.05
Tandanus tandanus	Freshwater catfish	722	0	0.17	0.87	0.19	0.40	0.87

Table 4. RCE and fish habitat scores for sites in the study area. See Appendix 2 for derivation of RCE scores and Appendix 3 for derivation of fish habitat classification. Ns = site not sampled.

Site	RCE Score	Fish Habitat Classfication	Reach	Location of Site
W1	44	1	1	Upstream of proposed innudation area
W2	37	1	1	Upstream of proposed innudation area
W3	39	1	2	Within proposed innundation area
W4	41	1	2	Within proposed innundation area
W5	40	1	2	Within proposed innundation area
W6	43	1	2	Within proposed innundation area
W7	40	1	3	Downstream of proposed innudation area & upstream of Chichester River confluence
W8	38	1	3	Downstream of proposed innudation area & upstream of Chichester River confluence
W9	35	1	3	Downstream of Chichester River confluence & upstream of Dungog
W10	38	1	3	Downstream of Chichester River confluence & upstream of Dungog
W11	ns	ns	3	Downstream of Dungog & upstream of Seaham Weir pool
W12	ns	ns	3	Downstream of Dungog & upstream of Seaham Weir pool

Table 5. Mean water quality at upstream locations in comparison with ANZECC (2000) physical and chemcial stressor guidelines for the protection of aquatic ecosystems for upland rivers* (Sites W1 & W2) and lowland rivers** (W3 - W10) in south–east Australia. Nutrient and Chlorophyll *a* analysis done by National Measurement Institute. See Appendix 4 and 5 for mean values ± S.E.. DO = Dissolved Oxygen, NO_x = Nitrate and Nitrate, TN = Total Nitrogen, TP = Total Phosphorus. ↓ = below lower trigger value, ↑ = above upper trigger value, ✓ = within trigger value range or below singular trigger value, ns = site not sampled, na = not applicable - monitoring of periphyton and not phytoplankton is recommended in upland rivers but values for periphyton biomass are to be developed, @ = conductivity values for NSW lowland rivers typically range from 200 - 300 µS cm^{-1}. Upland rivers are defined as > 150 m and < 1 500 m. Lowland rivers are defined as ≤ 150 m.

Reach	Site	pH * 6.5 - 8.0 **6.5 - 8.5	Conductivity (µS cm^{-1}) * 30 - 350 **125 - 2200@	Turbidity (ntu) * 2 - 25 **6 - 50	DO (% Sat.) * 90 - 110 **85 - 110	Chlorophyll *a* (µg L^{-1}) * na **5	NO_x (µg L^{-1}) * 15 **40	TN (µg L^{-1}) * 250 **500	TP (µg L^{-1}) * 20 **50
Reach 1	W1	↓	✓	✓	✓	na	↑	✓	↑
	W2	✓	✓	✓	↓	na	↑	✓	↑
Reach 2	W3	✓	↓	✓	↓	ns	ns	ns	ns
	W4	✓	↓	↓	↓	✓	✓	✓	↑
	W5	✓	✓	✓	↓	ns	ns	ns	ns
	W6	✓	↓	✓	↓	✓	↑	✓	↑
Reach 3	W7	✓	↓	✓	↓	ns	ns	ns	ns
	W8	✓	↓	✓	↓	✓	↑	✓	↑
	W9	✓	↓	↑	↓	✓	✓	✓	✓
	W10	✓	↓	✓	↓	✓	↑	✓	↑
	W11	ns	ns	ns	ns	✓	↑	✓	↑
	W12	ns	ns	ns	ns	✓	↑	↑	↑
Reach 4	SWP - S	✓	✓	↓	↓	↑	↑	✓	↑
	SWP - B	✓	✓	✓	↓	✓	↑	✓	↑

Table 6. Mean water quality at upstream locations in comparison with ANZECC (2000) toxicant guidelines for the protection of aquatic ecosystems. Trigger values for toxicants apply to *slightly-moderately disturbed systems* . Metal and non-metal inoganics analysis done by National Measurement Institute. See Appendix 6 for mean values ± S.E. ↑ = above trigger value, ✓ = below trigger value, ns = site not sampled, BDL = relative toxicity unknown as trigger value is lower than the detection limit of the analysis used

Reach	Site	Arsenic (µg L^{-1})	Cadmium (µg L^{-1})	Chromium (µg L^{-1})	Copper (µg L^{-1})	Lead (µg L^{-1})	Mercury (µg L^{-1})	Zinc (µg L^{-1})
		13	0.2	1	1.4	3.4	0.06	8
Reach 1	W1	✓	✓	✓	↑	✓	BDL	↑
	W2	✓	✓	✓	✓	✓	BDL	↑
Reach 2	W3	ns	ns	ns	ns	ns	ns	ns
	W4	✓	✓	✓	✓	✓	BDL	↑
	W5	ns	ns	ns	ns	ns	ns	ns
	W6	✓	✓	✓	↑	✓	BDL	↑
Reach 3	W7	ns	ns	ns	ns	ns	ns	ns
	W8	✓	✓	✓	↑	✓	BDL	↑
	W9	✓	✓	✓	✓	✓	BDL	↑
	W10	✓	✓	✓	✓	✓	BDL	↑
	W11	✓	✓	✓	↑	✓	BDL	↑
	W12	✓	✓	✓	↑	✓	BDL	↑
Reach 4	SWP - S	✓	✓	✓	✓	✓	↑	↑
	SWP - B	✓	✓	✓	✓	✓	↑	↑

Table 7. Mean water quality at upstream locations in comparison with ANZECC (2000) toxicant guidelines for the protection of aquatic ecosystems . Trigger values for toxicants apply to *slightly-moderately disturbed systems* . Organochlorine pesticide analysis done by National Measurement Institute. See Appendix 7 for full list of pesticides tested. ID = Insufficinent data to derive a reliable trigger value, value in brackets (x) is a derived low reliability freshwater trigger value, ↑ = above trigger value, ✓ = below trigger value, ns = site not sampled, ID = unknown as there is Insufficient Data to derive a reliable trigger value, BDL = unknown as trigger value is Below Detection Limit of the analysis used.

Reach	Site	Aldrin (μg L^{-1})	Chlordane (μg L^{-1})	DDE (μg L^{-1})	DDT (μg L^{-1})	Dieldrin (μg L^{-1})	Endosulfan (μg L^{-1})	Endosulfan alpha (μg L^{-1})	Endosulfan beta (μg L^{-1})	Endrin (μg L^{-1})	Heptachlor (μg L^{-1})	Lindane (μg L^{-1})	Methoxychlor (μg L^{-1})
		ID (0.001)	0.03	ID (0.03)	0.006	ID (0.01)	0.03	ID (0.0002)	ID (0.007)	0.01	0.01	0.2	ID (0.005)
Reach 1	W1	ID (BDL)	✓	ID (✓)	BDL	ID (✓)	✓	ID (BDL)	ID (BDL)	✓	✓	✓	ID (BDL)
	W2	ID (BDL)	✓	ID (✓)	BDL	ID (✓)	✓	ID (BDL)	ID (BDL)	✓	✓	✓	ID (BDL)
Reach 2	W3	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	W4	ID (BDL)	✓	ID (✓)	BDL	ID (✓)	✓	ID (BDL)	ID (BDL)	✓	✓	✓	ID (BDL)
	W5	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	W6	ID (BDL)	✓	ID (✓)	BDL	ID (✓)	✓	ID (BDL)	ID (BDL)	✓	✓	✓	ID (BDL)
Reach 3	W7	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	W8	ID (BDL)	✓	ID (✓)	BDL	ID (✓)	✓	ID (BDL)	ID (BDL)	✓	✓	✓	ID (BDL)
	W9	ID (BDL)	✓	ID (✓)	BDL	ID (✓)	✓	ID (BDL)	ID (BDL)	✓	✓	✓	ID (BDL)
	W10	ID (BDL)	✓	ID (✓)	BDL	ID (✓)	✓	ID (BDL)	ID (BDL)	✓	✓	✓	ID (BDL)
	W11	ID (BDL)	✓	ID (✓)	BDL	ID (✓)	✓	ID (BDL)	ID (BDL)	✓	✓	✓	ID (BDL)
	W12	ID (BDL)	✓	ID (✓)	BDL	ID (✓)	✓	ID (BDL)	ID (BDL)	✓	✓	✓	ID (BDL)
Reach 4	SWP - S	ID (BDL)	✓	ID (✓)	BDL	ID (✓)	✓	ID (BDL)	ID (BDL)	✓	✓	✓	ID (BDL)
	SWP - B	ID (BDL)	✓	ID (✓)	BDL	ID (✓)	✓	ID (BDL)	ID (BDL)	✓	✓	✓	ID (BDL)

Table 8. Summary of AusRivAS analysis for a) Spring edge 2007 b) Spring riffle 2007. Bands based on OE50 (see Appendix 11 for upper limits). See methods for desription of other variables; Appendix 10 for raw data. ns: site not sampled due to elevated river height.

a) Edge

Reach	Site	Band	OE50	NTE50	NTC50	O0Signal	OE0Signal	Signal2
Reach 1	W1	X	1.25	13.62	17	4.87	1.05	4.94
	W2	A	1.05	14.32	15	4.16	0.96	4.20
Reach 2	W3	A	0.93	15.05	14	4.52	1.05	4.36
	W4	A	1.12	14.35	16	4.84	1.12	5.00
	W5	X	1.26	15.04	19	4.48	1.04	4.41
	W6	A	1.04	14.48	15	4.27	1	4.26
Reach 3	W7	B	0.8	15.04	12	4.17	0.97	4.00
	W8	A	0.93	15.06	14	4.4	1.03	4.71
	W9	B	0.59	10.23	6	3.67	0.91	3.50
	W10	A	0.93	15.08	14	3.95	0.92	4.00
	W11	ns	ns	ns	ns	ns	ns	ns
	W12	ns	ns	ns	ns	ns	ns	ns

a) Riffle

Reach	Site	Band	OE50	NTE50	NTC50	O0Signal	OE0Signal	Signal2
Reach 1	W1	A	1.16	14.71	17	5.52	0.94	5.68
	W2	A	0.93	16.21	15	5.28	0.93	5.63
Reach 2	W3	A	1.06	15.06	16	5.87	1.06	6.09
	W4	A	1.15	15.71	18	5.54	1	5.54
	W5	A	1.14	15.82	18	5.14	0.94	5.14
	W6	A	1.07	15.93	17	5.62	1.03	5.65
Reach 3	W7	A	0.93	16.05	15	5.46	1.01	5.50
	W8	B	0.78	16.61	13	5.89	1.09	5.89
	W9	A	0.96	16.69	16	5	0.93	5.13
	W10	B	0.65	16.92	11	5.15	0.97	5.15
	W11	ns	ns	ns	ns	ns	ns	ns
	W12	ns	ns	ns	ns	ns	ns	ns

Table 9. Total fish abundances by site for electrofisher (n = 3) and bait traps (n = 10)

		W1		W2		W3		W4		W5		W6		W7		W8		W9		W10		**Total**
Scientific Name	Common Name	Electro	Bait	Electro	Bait	Electro	Bait	Electro	Bait	Electro	Bait	Electro	Bait	Electro	Bait	Electro	Bait	Electro	Bait	Electro	Bait	
Gobiomorphus coxii	Coxs gudgeon	2	2	7	1	11	0	1	1	3	0	0	1	2	0	4	0	1	0	1	0	**37**
Gobiomorphus australis	Striped gudgeon	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	**2**
Philypnodon grandiceps	Flathead gudgeon	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Retropinna semoni	Australian smelt	0	0	63	0	35	0	13	0	23	45	6	0	88	61	56	0	73	5	51	0	**519**
Anguilla reinhardtii	Longfinned eel	1	0	5	0	1	0	6	0	8	0	3	0	3	0	6	0	0	0	1	0	**34**
Gambusia holbrooki	Plague minnow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	**2**

Table 10. Comparison of fish assemblages by reach, before and (hypothetically) after the construction of theTilegra Dam. # = alien species. ✓= Species present, ✓ ? = Cox's gudgeon may persist although it has been extirpated above dams in other rivers, ? = persistence depends on interacting effects of Tillegra Dam with Seaham Weir on fish passage.

Scientific Name	Common Name	Reach 1: Upstream of inundation area		Reach 2: Inundation area		Reach 3: Dam wall to Glen Martin		Reach 4: Glen Martin to Seaham Weir	
		Before	After	Before	After	Before	After	Before	After
Anguilla australis	Shortfinned eel	✓	✓	✓	✓	✓	✓	✓	✓
Anguilla reinhardtii	Longfinned eel	✓	✓	✓	✓	✓	✓	✓	✓
Potamalosa richmondia	Freshwater herring	✓		✓		✓	?	✓	?
Gambusia holbrooki	Gambusia#	✓	✓	✓	✓	✓	✓	✓	✓
Mugil cephalus	Sea mullet	✓		✓		✓	?	✓	?
Myxus petardi	Freshwater mullet	✓		✓		✓	?	✓	?
Retropinna semoni	Australian smelt	✓	✓	✓	✓	✓	✓	✓	
Gobiomorphus australis	Striped gudgeon	✓		✓		✓	?	✓	?
Gobiomorphus coxii	Cox's gudgeon	✓	✓?	✓	✓?	✓	✓	✓?	✓?
Hypseleotris compressa	Empire gudgeon					✓	?	✓	?
Philypnodon grandiceps	Flathead gudgeon	✓	✓	✓	✓	✓	✓	✓	✓
Philypnodon sp.	Dwarf flathead gudgeon	✓	✓	✓	✓	✓	✓	✓	✓
Macquaria novemaculeata	Australian bass	✓		✓		✓	?	✓	?
Notesthes robusta	Bullrout					✓	?	✓	?
Tandanus tandanus	Freshwater catfish	✓	✓	✓	✓	✓	✓	✓	✓

Table 11. Illustrative breeding/migration patterns of fish that have been sampled in the study area.

Spawning
Downstream migration
Upstream migration
Possible breeding season

Common name	Movement/activity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Catadromous													
Short-finned eel	Downstream migration of adults	X	X	X	X	X					X	X	X
	Recruitment of glass eels from sea to estuaries					X	X	X	X	X	X		
	Upstream migration of brown elvers	X									X	X	X
Long-finned eel	Downstream migration of adults	X	X	X	X	X							
	Recruitment of glass eels from sea to estuaries	X	X	X	X	X							
	Upstream migration from estuaries to freshwater	X	X	X	X							X	X
Freshwater herring	Spawning						X	X	X				
	Downstream migration to spawn						X	X	X				
Sea mullet	Adults spawn in ocean				X	X	X	X					
Freshwater mullet	Spawning	X	X	X									
	Downstream migration of adults to estuaries	X	X	X									X
Australian bass	Spawning					X	X	X	X	X	P	P	P
	Downstream migration of adults to estuaries				X	X	X	X					
	Upstream migration of adults to freshwater								X	X	X		
	Upstream migration of juveniles to freshwater	X	X	X	X						X	X	X
Bullrout	Spawning				X	X	X	X					
	Upstream migration of adults						X	X	X	X			

Continued…..

Table 11. Continued

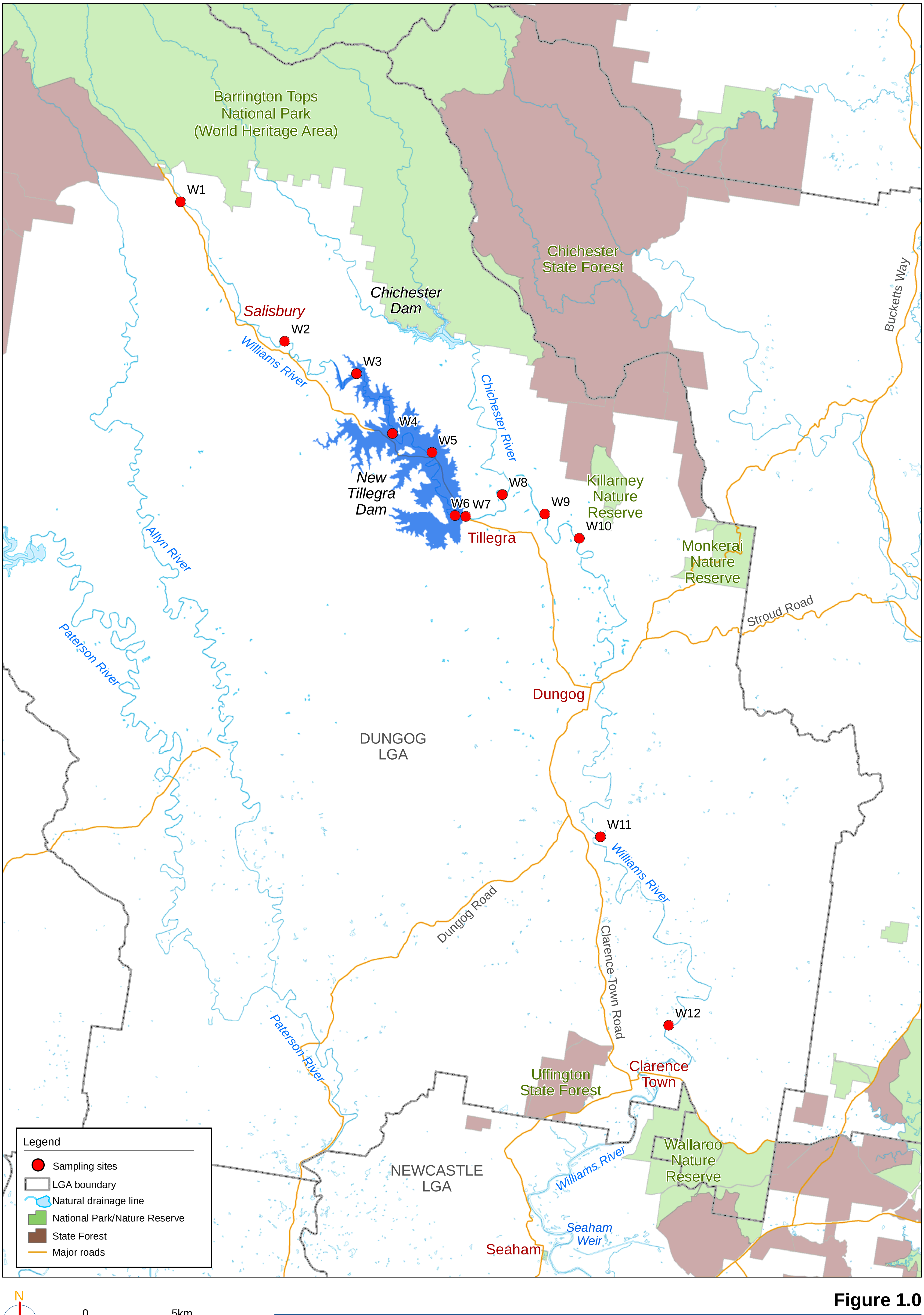
Common name	Movement/activity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Amphidromous													
Striped gudgeon	Spawning												
	Larvae carried downstream												
	Juvenilles begin upstream migration												
Cox's gudgeon	Spawning												
	Larvae carried downstream												
	Upstream migration of juveniles												
Empire gudgeon	Spawning												
	Larvae carried downstream												
Potamodromous & Undefined													
Mosquitofish	Breeding												
Australian smelt	Spawning												
Flatheaded gudgeon	Spawning												
Dwarf flathead gudgeon	Spawning												
Freshwater catfish	Spawning												

Table 12. Recorded swimming abilities of fish that occur within the Williams River, or are closely related to fish that occur within the Williams River. Maximum velocities (m/s) during sustained and burst swimming are indicated. Note: Mallen-Cooper's (1992) estimates are "negotiable velocity" and relate to the ability of 95% of a test population to negotiate a velocity barrier at the velocities specified. Empire gudgeon were observed negotiating a weir in Queensland (in Pusey *et al*. 2004). All other values are neutral with respect to water velocity. Sources of data include: Mitchell 1989, Mallen-Cooper 1992, Langdon & Collins 2000, Pusey *et al*. 2004.

Species or Cogeneric	Common Name	Length (LCF, mm)	Approximate life history stage	Prolonged swimming		Burst swimming	
				m/s	Duration (secs)	m/s	Duration (secs)
Anguilla australis	Shortfinned eel	55 - 80	Elver	0.34	35 - 1000	0.57	4 - 30
		54	Glass eels	0.29	≥ 300	0.79	3 - 24
Anguilla reinhardtii	Longfinned eel	51	Glass eels	0.32	≥ 300	0.75	3 - 24
Mugil cephalus	Sea mullet	40	Small juvenile	-	-	1.45	2
		86 - 130	Juvenile	-	-	1.60	2
Retropinna retropinna	NZ smelt	56 - 67	Adult	0.27	35 - 1000	0.50	4 - 30
Gobiomorphus cotidianus	NZ common bully	30 - 42	Small Juvenile	0.28	35 - 1000	0.60	4 - 30
Hypseleotris compressa	Empire gudgeon	-	-	-	-	1.00	-
Macquaria novemaculeata	Australian bass	40	Small juvenile	-	-	1.02	-
		64	Juvenile	-	-	1.40	-
		93	Large Juvenile	-	-	1.84	-

FIGURES

Figure 1: The Williams River study area, Sites W1 – W12.



Source: Base data - HWC & NSW Dept. of Lands 2007
Sampling sites - The Ecology Lab 2007

Figure 1.0

Sampling Sites

PLATES

Plate 1a – 1d: Sites upstream of proposed inundation area (a) Site W1, looking downstream from top of site (b) Site W1, looking upstream from bottom of site, (c) Site W2, looking downstream from top of site (d) Site W2, looking upstream from bottom of site.

Plate 2a – 2d: Sites within proposed inundation area (a) Site W3, looking downstream from top of site (b) Site W3, looking upstream from bottom of site, (c) Site W4, looking downstream from top of site (d) Site W4, looking upstream from bottom of site.

Plate 3a – 3d: Sites within proposed inundation area (a) Site W5, looking downstream from top of site (b) Site W5, looking upstream from bottom of site, (c) Site W6, looking downstream from top of site (d) Site W6, looking upstream from bottom of site.

Plate 4a – 4d: Sites downstream of proposed inundation area (a) Site W7, looking downstream from top of site (b) Site W7, looking upstream from bottom of site, (c) Site W8, looking downstream from top of site (d) Site W8, looking upstream from bottom of site.

Plate 5a – 5d: Sites downstream of proposed inundation area (a) Site W9, looking downstream from top of site (b) Site W9, looking upstream from bottom of site, (c) Site W10, looking downstream from top of site (d) Site W10, looking upstream from bottom of site.

Plate 6a – 6d: Freshwater fish sampled in the Williams River (a) Cox's gudgeon, (b) Striped gudgeon, (c) Flathead gudgeon (d) Australian smelt.

(a)

(b)

(c)

(d)

Plate 1a – 1d: Sites upstream of proposed inundation area (a) Site W1, looking downstream from top of site (b) Site W1, looking upstream from bottom of site, (c) Site W2, looking downstream from top of site (d) Site W2, looking upstream from bottom of site.

(a)

(b)

(c)

(d)

Plate 2a – 2d: Sites within proposed inundation area (a) Site W3, looking downstream from top of site (b) Site W3, looking upstream from bottom of site, (c) Site W4, looking downstream from top of site (d) Site W4, looking upstream from bottom of site.

(a)

(b)

(c)

(d)

Plate 3a – 3d: Sites within proposed inundation area (a) Site W5, looking downstream from top of site (b) Site W5, looking upstream from bottom of site, (c) Site W6, looking downstream from top of site (d) Site W6, looking upstream from bottom of site.

(a)

(b)

(c)

(d)

Plate 4a – 4d: Sites downstream of proposed inundation area (a) Site W7, looking downstream from top of site (b) Site W7, looking upstream from bottom of site, (c) Site W8, looking downstream from top of site (d) Site W8, looking upstream from bottom of site.

(a)

(b)

(c)

(d)

Plate 5a – 5d: Sites downstream of proposed inundation area (a) Site W9, looking downstream from top of site (b) Site W9, looking upstream from bottom of site, (c) Site W10, looking downstream from top of site (d) Site W10, looking upstream from bottom of site.

(a)

(b)

(c)

(d)

Plate 6a – 6d: Freshwater fish sampled in the Williams River (a) Cox's gudgeon, (b) Striped gudgeon, (c) Flathead gudgeon (d) Australian smelt.

APPENDICES

Appendix 1: GPS coordinates of the study sites (Datum WGS84) recorded on sampling dates in November and December 2007

Appendix 2: River descriptors, associated categories and values used in the modified riparian, channel and environmental inventory (RCE) From Chessman et al. (1997).

Appendix 3: Fish habitat classification criteria for watercourses and recommended crossings types.

Appendix 4: Mean (± S.E., n =2) physical water quality indicators recorded in situ. Field data recorded by The Ecology Lab.

Appendix 5: Mean (± S.E., n = 2) concentrations of nutrients, anions, suspended solids, faecal coliform and chlorophyll a in water.

Appendix 6: Mean (± S.E., n = 2) trace element concentrations in water.

Appendix 7: List of pesticides tested for in Williams River water quality samples.

Appendix 8: Depth profile of physical water quality indicators at Seaham Weir pool recorded in situ every 0.5 m.

Appendix 9: Summary statistics for AusRivAS macroinvertebrate assemblages and Signal2 scores.

Appendix 10: AusRivAS macroinvertebrate assemblage data for edge and riffle habitats from sampling sites in the Williams River with Signal2 scores

Appendix 11: Summary of AusRivAS Bands for NSW a) Spring edge b) Spring riffle.

Appendix 1. GPS coordinates (Datum WGS84) and distances of the study sites and reaches from sampling in November and December 2007. Values in italics are provisional, as sampling was not done due to elevated river levels. ns = not sampled.

Site	Location	Reach	Topographic Map	Upstream boundary Easting	Upstream boundary Northing	Downstream boundary Easting	Downstream boundary Northing	Sampling Date
W1	Upstream of proposed innudation area	1	Chichester	361880	6439807	361948	6439745	26/11/07
W2	Upstream of proposed innudation area	1	Chichester	367296	6432547	367430	6432533	27/11/07
W3	Within proposed innundation area	2	Allynbrook	371023	6430879	371086	6430925	26/11/07
W4	Within proposed innundation area	2	Allynbrook	372888	6427766	372890	6427672	28/11/07
W5	Within proposed innundation area	2	Allynbrook	374949	6426790	375011	6426716	27/11/07
W6	Within proposed innundation area	2	Allynbrook	376149	6423500	376175	6423389	27/11/07
W7	Downstream of proposed innudation area & upstream of Chichester River confluence	3	Allynbrook	376699	6423457	376780	6423422	3/12/07
W8	Downstream of proposed innudation area & upstream of Chichester River confluence	3	Allynbrook	378599	6424587	378676	6424620	3/12/07
W9	Downstream of Chichester River confluence & upstream of Dungog	3	Allynbrook	380808	6423576	380939	6423589	4/12/07
W10	Downstream of Chichester River confluence & upstream of Dungog	3	Allynbrook	382601	6422320	382606	6422220	4/12/07
W11	Downstream of Dungog & upstream of Seaham Weir pool	3	Dungog	*383704*	*6406824*			ns
W12	Downstream of Dungog & upstream of Seaham Weir pool	3	Clarence Town	*387245*	*6397027*			ns

Reach No.	Reach Extent	Reach Length (km)	Sampling Sites	Distance From Last Site (km)	Site Distance from Williams River Headwaters (km)
1	Upper Williams from top of catchment to the storage full supply level (FSL)	34	W1	0	16
			W2	11	27
2	Storage	19 at FSL	W3	8	35
			W4	7	42
			W5	3	45
			W6	7	52
3	Tillegra Bridge to Glen Martin	63	W7	1	53
			W8	3	56
			W9	3	58
			W10	5	64
			W11	14	78
			W12	37	115
4	Seaham Weir Pool	23	SWP	24	139
5	Seaham Weir to Hunter River Confluence	15	N/A	N/A	N/A

Appendix 2. River descriptors, associated categories and values used in the modified riparian, channel and environmental inventory (RCE) From Chessman *et al* . (1997).

Descriptor and category	Score	Descriptor and category	Score
1. Land use pattern beyond the immediate riparian zone		8. Riffle / pool sequence	
Undisturbed native vegetation	4	Frequent alternation of riffles and pools	4
Mixed native vegetation and pasture/exotics	3	Long pools with infrequent short riffles	3
Mainly pasture, crops or pine plantation	2	Natural channel without riffle / pool sequence	2
Urban	1	Artificial channel; no riffle / pool sequence	1
2. Width of riparian strip of woody vegetation		9. Retention devices in stream	
More than 30 m	4	Many large boulders and/or debris dams	4
Between 5 and 30 m	3	Rocks / logs present; limited damming effect	3
Less than 5 m	2	Rocks / logs present, but unstable, no damming	2
No woody vegetation	1	Stream with few or no rocks / logs	1
3. Completeness of riparian strip of woody vegetation		10. Channel sediment accumulations	
Riparian strip without breaks in vegetation	4	Little or no accumulation of loose sediments	4
Breaks at intervals of more than 50 m	3	Some gravel bars but little sand or silt	3
Breaks at intervals of 10 - 50 m	2	Bars of sand and silt common	2
Breaks at intervals of less than 10 m	1	Braiding by loose sediment	1
4. Vegetation of riparian zone within 10 m of channel		11. Stream bottom	
Native tree and shrub species	4	Mainly clean stones with obvious interstices	4
Mixed native and exotic trees and shrubs	3	Mainly stones with some cover of algae / silt	3
Exotic trees and shrubs	2	Bottom heavily silted but stable	2
Exotic grasses / weeds only	1	Bottom mainly loose and mobile sediment	1
5. Stream bank structure		12. Stream detritus	
Banks fully stabilised by trees, shrubs etc	4	Mainly unsilted wood, bark, leaves	4
Banks firm but held mainly by grass and herbs	3	Some wood, leaves etc. with much fine detritus	3
Banks loose, partly held by sparse grass etc	2	Mainly fine detritus mixed with sediment	2
Banks unstable, mainly loose sand or soil	1	Little or no organic detritus	1
6. Bank undercutting		13. Aquatic vegetation	
None, or restricted by tree roots	4	Little or no macrophyte or algal growth	4
Only on curves and at constrictions	3	Substantial algal growth; few macrophytes	3
Frequent along all parts of stream	2	Substantial macrophyte growth; little algae	2
Severe, bank collapses common	1	Substantial macrophyte and algal growth	1
7. Channel form			
Deep: width / depth ratio less than 7:1	4		
Medium: width / depth ratio 8:1 to 15:1	3		
Shallow: width / depth ratio greater than 15:1	2		
Artificial: concrete or excavated channel	1		

Appendix 3. Fish habitat classification criteria for watercourses and recommended crossings types (Source: Fairfull and Witheridge, 2003).

Classification	Characteristics of Waterway Type	Minimum Recommended Crossing Type
Class 1 – Major Fish Habitat	Major permanently or intermittently flowing waterway (e.g. river or major creek), habitat of a threatened fish species.	Bridge, arch structure or tunnel.
Class 2 – Moderate fish habitat	Named permanent or intermittent stream, creek or waterway with clearly defined bed and banks and with semi-permanent to permanent waters in pools or in connected wetland areas. Marine or freshwater aquatic vegetation is present. Known fish habitat and / or fish observed inhabiting the area.	Bridge, arch structure, culvert or ford.
Class 3 – Minimal fish habitat	Named or unnamed waterway with intermittent flow and potential refuge, breeding or feeding areas for some aquatic fauna (e.g. fish, yabbies). Semi-permanent pools form within the waterway or adjacent wetlands after a rain event. Otherwise, any minor waterway that interconnects with wetlands or recognised aquatic habitats.	Culvert or ford
Class 4 – Unlikely fish habitat	Named or unnamed watercourse with intermittent flow during rain events only, little or no defined drainage channel, little or no free standing water or pools after rain event (e.g. dry gullies or shallow floodplain depression with no permanent wetland aquatic flora present).	Culvert, causeway or ford

Appendix 4. Mean (± S.E., n =2) physical water quality indicators recorded *in situ* . Field data recorded by The Ecology Lab.

Reach	Site	pH		Salinity (ppt)		Conductivity (µS cm^{-1})		Conductivity (mS cm^{-1})		Temperature (^{0}C)		Turbidity (ntu)		Dissolved Oxygen (mg L^{-1})		Dissolved Oxygen (%Saturation)		ORP (mV)		Alkalinity ($CaCO_2$ mgL^{-1})
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Single Reading
Reach 1	W1	6.30	0.15	0.03	0.00	75.0	2.0	0.06	0.00	17.14	0.01	4.7	2.0	8.75	0.15	91.15	1.45	479.0	9.0	20
	W2	6.78	0.07	0.05	0.00	118.0	0.0	0.09	0.00	20.26	0.05	3.5	0.1	8.05	0.05	89.15	1.05	534.5	0.5	26
Reach 2	W3	6.75	0.10	0.03	0.00	102.0	0.0	0.07	0.00	22.21	0.02	10.1	0.2	7.10	0.00	81.80	0.40	455.5	4.5	31
	W4	6.89	0.01	0.07	0.00	123.0	0.0	0.09	0.00	21.62	0.04	4.1	0.3	7.10	0.00	80.75	0.15	471.5	3.5	28
	W5	6.77	0.12	0.05	0.00	125.0	0.0	0.11	0.00	21.43	0.00	14.0	1.7	6.50	0.00	73.55	0.25	487.5	2.5	32
	W6	6.89	0.10	0.05	0.00	117.0	0.0	0.10	0.00	24.10	0.01	11.3	0.5	6.95	0.15	82.85	1.25	521.0	1.0	35
Reach 3	W7	6.67	0.25	0.05	0.00	105.0	0.0	0.11	0.00	22.43	0.02	23.3	0.2	6.60	0.00	76.00	0.10	461.0	5.0	30
	W8	7.07	0.05	0.05	0.00	117.0	0.0	0.10	0.00	23.01	0.01	22.9	1.3	6.05	0.05	70.45	0.15	464.0	3.0	32
	W9	7.40	0.00	0.03	0.00	89.5	6.5	0.07	0.00	20.86	0.01	51.7	0.7	6.05	0.05	67.95	0.55	457.5	3.5	33
	W10	7.33	0.00	0.01	0.00	55.0	0.0	0.03	0.00	21.65	0.03	44.6	0.8	6.35	0.05	72.20	0.30	477.5	1.5	38

Appendix 5. Mean (± S.E., n = 2) concentrations of nutrients, anions, suspended solids, faecal coliform and chlorophyll *a* in water. Samples collected by The Ecology Lab and analysed by the National Measurement Institute (NMI) and Sonic Food & Water Testing. ns = samples not taken at this site.

Reach	Site	Faecal Coliform (colony forming units $100ml^{-1}$)		Chlorophyll *a* ($mg\ L^{-1}$)		Chloride ($mg\ L^{-1}$)		Total Nitrogen ($mg\ L^{-1}$)		NOx ($mg\ L^{-1}$)		Sulphate (mg L-1)		Suspended Solids ($mg\ L^{-1}$)		Total Kjeldahl Nitrogen ($mg\ L^{-1}$)	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Reach 1	W1	ns	ns	ns	ns	9.15	0.05	0.14	0.01	0.02	0.00	3.50	0.10	7.0	3.0	0.11	0.00
	W2	ns	ns	ns	ns	5.80	0.00	<0.05	<0.05	0.02	0.00	2.30	0.00	3.5	1.5	<0.05	<0.05
Reach 2	W3	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	W4	ns	ns	ns	ns	11.00	0.00	0.20	0.03	0.03	0.00	4.10	0.00	<2.0	<2.0	0.16	0.02
	W5	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	W6	ns	ns	<0.001	0.000	13.00	0.00	0.18	0.03	0.04	0.00	4.60	0.00	12.5	1.5	0.14	0.04
Reach 3	W7	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	W8	2950	550	ns	ns	13.00	0.00	0.34	0.06	0.05	0.00	4.35	0.05	21.0	1.0	0.29	0.06
	W9	900	200	0.001	0.001	10.00	0.00	0.22	0.03	0.03	0.00	3.30	0.10	12.0	0.0	0.19	0.03
	W10	ns	ns	<0.001	0.000	10.50	0.50	0.30	0.00	0.04	0.00	3.20	0.10	13.0	0.0	0.26	0.00
	W11	2950	550	<0.001	0.000	12.00	0.00	0.49	0.03	0.05	0.00	3.60	0.50	31.0	2.0	0.44	0.02
	W12	785	515	<0.001	0.000	18.00	0.00	0.80	0.40	0.09	0.03	4.65	0.05	44.0	5.0	0.72	0.39
Reach 4	SWP - S	<20	0	0.018	0.001	29.50	0.50	0.28	0.03	<0.01	<0.01	5.90	0.00	6.0	0.0	0.28	0.03
	SWP - B	<20	0	0.001	0.001	41.00	1.00	0.45	0.05	0.08	0.01	6.35	0.05	17.5	1.5	0.37	0.04

Appendix 6. Mean (± S.E., n = 2) trace element concentrations in water. Samples collected by The Ecology Lab and analysed by the National Measurement Institute (NMI). ns = samples not taken at this site.

Reach	Site	Arsenic ($mg\ L^{-1}$)		Cadmium ($mg\ L^{-1}$)		Chromium ($mg\ L^{-1}$)		Copper ($mg\ L^{-1}$)		Lead ($mg\ L^{-1}$)		Mercury ($mg\ L^{-1}$)		Total Phosphorus ($mg\ L^{-1}$)		Zinc ($mg\ L^{-1}$)	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Reach 1	W1	<0.001	0	<0.001	0	0.001	0	0.002	0.001	<0.001	0	<0.0001	0	0.048	0.023	0.019	0
	W2	<0.001	0	<0.001	0	<0.001	0	<0.001	0	<0.001	0	<0.0001	0	0.038	0.013	0.016	0.001
Reach 2	W3	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	W4	<0.001	0	<0.001	0	0.001	0	0.001	0	<0.001	0	<0.0001	0	0.064	0.006	0.019	0.002
	W5	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	W6	<0.001	0	<0.001	0	0.001	0	0.002	0	<0.001	0	<0.0001	0	0.073	0.001	0.021	0.006
Reach 3	W7	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	W8	<0.001	0	<0.001	0	0.001	0	0.002	0	<0.001	0	<0.0001	0	0.087	0.007	0.017	0.001
	W9	<0.001	0	<0.001	0	<0.001	0	0.001	0	<0.001	0	<0.0001	0	0.040	0.015	0.018	0.002
	W10	<0.001	0	<0.001	0	<0.001	0	0.001	0	<0.001	0	<0.0001	0	0.074	0.001	0.013	0.002
	W11	0.001	0	<0.001	0	0.001	0	0.002	0	<0.001	0	<0.0001	0	0.110	0	0.016	0.002
	W12	0.001	0	<0.001	0	0.001	0	0.002	0	<0.001	0	<0.0001	0	0.090	0.011	0.020	0.004
Reach 4	SWP - S	0.001	0	<0.001	0	<0.001	0	0.001	0	<0.001	0	0.0002	0	0.079	0.006	0.013	0.002
	SWP - B	0.002	0	<0.001	0	<0.001	0	0.001	0	<0.001	0	0.0001	<0.0001	0.260	0.030	0.016	0.004

Appendix 7. List of pesticides tested for in Williams River water quality samples collected at Sites W1, W2, W4, W6, W8 to W12, SWP-S and SWP-B. Two samples were collected at each site ($n = 2$). All samples recorded concentrations beneath detection limits for all sites (<0.01 µg L^{-1})

HCB
Heptachlor
Heptachlor epoxide
Aldrin
gamma-BHC (Lindane)
alpha-BHC
beta-BHC
delta-BHC
trans-Chlordane
cis-Chlordane
Oxychlordane
Dieldrin
p,p-DDE
p,p-DDD
p,p-DDT
Endrin
Endrin Aldehyde
Endrin Ketone
alpha-Endosulfan
beta-Endosulfan
Endosulfan Sulfate
Methoxychlor

Appendix 8. Depth profile of physical water quality indicators at Seaham Weir pool recorded *in situ* every 0.5 m. Field data recorded by The Ecology Lab.

Depth (m)	Temperature (^{0}C)	Conductivity (mS cm^{-1})	Conductivity (µS cm^{-1})	Salinity (ppt)	pH	ORP (mV)	Dissolved Oxygen (% Saturation)	Dissolved Oxygen (mg L^{-1})	Mean Turbidity (± SE) (ntu)
0.5	26.45	0.214	213	0.10	7.26	450	72.8	5.8	4.7 (± 0.1)
1.0	25.87	0.213	213	0.10	7.26	456	69.0	5.6	5.5 (± 0.1)
1.5	25.74	0.213	213	0.10	7.25	462	65.8	5.4	4.5 (± 0.1)
2.0	25.49	0.213	213	0.10	7.25	467	66.5	5.5	4.2 (± 0.1)
2.5	25.23	0.213	213	0.10	7.17	473	56.2	4.8	4.3 (± 0.0)
3.0	24.76	0.212	211	0.10	7.09	476	42.8	3.5	4.2 (± 0.1)
3.5	24.17	0.208	207	0.10	7.03	480	30.6	2.6	4.5 (± 0.1)
4.0	23.48	0.212	214	0.10	6.98	481	17.6	1.5	6.0 (± 0.3)
4.5	22.89	0.228	227	0.11	6.94	418	7.2	0.6	8.0 (± 0.1)
5.0	21.41	0.258	258	0.12	7.02	280	2.0	0.2	16.2 (± 0.3)
5.5	20.95	0.265	266	0.13	6.98	241	1.4	0.1	17.2 (± 0.2)
6.0	20.59	0.271	271	0.13	7.00	217	1.2	0.1	17.3 (± 0.2)
6.5	20.39	0.273	274	0.13	7.05	193	1.3	0.1	16.0 (± 0.5)
7.0	19.95	0.276	276	0.13	7.06	149	0.9	0.1	13.8 (± 0.4)
7.5	19.89	0.277	276	0.13	7.08	134	0.9	0.1	14.0 (± 0.1)
8.0	19.84	0.277	277	0.13	7.09	125	0.9	0.1	13.1 (± 0.1)

Appendix 9. Summary statistics for AusRivAS macroinvertebrate assemblages and Signal2 scores (as per Chessman 2003).

	W1		W2		W3		W4		W5		W6		W7		W8		W9		W10		Total	Total	Total
Totals	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	No.
Individuals	**138**	**163**	**150**	**136**	**100**	**128**	**153**	**116**	**135**	**144**	**89**	**148**	**84**	**115**	**89**	**82**	**81**	**104**	**83**	**86**	**1102**	**1222**	**2324**
Worms	10	7	6	10	1	1	11	2	2	9	2	5	1	1	3	0	10	3	4	1	50	39	89
Crustaceans	5	1	15	0	12	1	11	1	12	10	11	0	10	1	10	0	3	3	10	0	99	17	116
Molluscs	0	0	5	1	0	0	5	1	2	1	3	3	5	3	10	0	4	3	3	2	37	14	51
Insects	112	145	112	116	86	118	123	106	109	122	73	137	63	108	64	81	44	92	59	76	845	1101	1946
Mayflies	24	31	17	27	11	19	24	23	15	28	13	33	10	32	14	19	1	30	9	22	138	264	402
Damselflies/dragonflies	14	12	18	13	18	9	24	6	17	16	14	20	7	17	6	2	0	5	2	4	120	104	224
Bugs	3	0	23	4	13	0	12	0	26	0	12	0	20	0	16	0	13	5	21	0	159	9	168
Beetles	19	21	7	20	15	20	24	15	23	22	11	20	11	16	10	15	19	16	11	17	150	182	332
True flies	33	34	24	20	6	12	9	9	12	20	6	22	3	6	3	10	9	14	5	9	110	156	266
Caddis-flies	14	30	22	28	23	45	28	36	16	35	17	40	12	37	14	33	1	18	9	24	156	326	482
Other insects	5	17	1	4	0	13	2	17	0	1	0	2	0	0	1	2	1	4	2	0	12	60	72
Other taxa	11	10	12	9	1	8	3	6	10	2	0	3	5	2	2	1	20	3	7	7	71	51	122
Taxa	**31**	**31**	**34**	**26**	**26**	**23**	**34**	**24**	**33**	**28**	**24**	**26**	**25**	**24**	**25**	**19**	**22**	**26**	**24**	**22**	**72**	**58**	**85**
Worm taxa	2	2	2	1	1	1	2	1	1	2	1	1	1	1	1	0	1	1	2	1	5	3	6
Crustacean taxa	1	1	3	0	2	1	2	1	3	2	2	0	1	1	1	0	3	1	1	0	6	3	7
Mollusc taxa	0	0	1	1	0	0	1	1	1	1	2	2	1	2	1	0	2	1	1	1	3	2	3
Insect taxa	26	27	25	22	22	20	27	20	26	22	19	22	20	19	21	18	13	21	17	18	54	47	65
Mayfly taxa	4	4	2	4	2	4	3	4	3	4	2	4	1	4	3	3	1	4	2	4	4	4	5
Damselfly/dragonfly tax	4	2	8	4	5	3	6	2	4	2	3	2	4	4	3	1	0	1	1	1	11	7	12
Bug taxa	3	0	3	1	3	0	2	0	4	0	3	0	4	0	3	0	3	2	3	0	6	2	6
Beetle taxa	4	3	4	2	3	2	4	2	6	4	4	2	5	2	5	2	4	3	3	4	7	7	9
True fly taxa	8	9	3	4	5	3	3	4	4	6	4	5	3	3	2	5	3	5	4	4	13	11	15
Caddis-fly taxa	2	7	4	6	4	6	7	5	5	5	3	7	3	6	4	6	1	4	2	5	8	13	13
Other insect taxa	1	1	0	0	0	1	0	1	0	1	0	1	0	0	0	0	0	1	1	0	2	1	2
Other taxa	2	1	3	2	1	1	2	1	2	1	0	1	2	1	1	1	3	2	3	2	4	3	4
																					Average		
																					Edge	Riffle	
Signal2 Score	4.9	5.7	4.2	5.6	4.4	6.1	5.0	5.5	4.4	5.1	4.3	5.7	4.0	5.5	4.7	5.9	3.5	5.1	4.0	5.2	**4.3**	**5.5**	

Appendix 10. AusRivAS macroinvertebrate assemblage data for edge and riffle habitats from sampling sites in the Williams River with Signal2 scores (as per Chessman 2003).

Order or Family	W1		W2		W3		W4		W5		W6		W7		W8		W9		W10		Total	Signal2
	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle		
Aeshnidae			1		1		1														3	4
Ameletopsidae		1		1		1		2		2		10		8		4		9		2	40	7
Araneae	1		1				1						4				2		1	2	12	
Athericidae	1	10		10	1	3		4		7	1	7		4		2				2	52	8
Atyidae	5	1	3		10	1	8	1	10	1	10		10		10			3	10		83	3
Baetidae	3	10		7		5	10	10	1	10		10		9	3	5	1	10		3	97	5
Caenidae	10	10	7	9	1	3	4	1	4	6	3	3		5	1			1	1	7	76	4
Calamoceratidae	4		10		10	7	9		1		6		1		2	2		1	5	10	68	7
Calocidae							2													1	3	9
Ceinidae																	1				1	2
Ceratopogonidae	3	2			1											1				1	8	4
Chironomidae																						
/Chironominae	10	10	10	6	2	6	3	3	5	5	2	4		1				2	1	3	73	3
/Diamesinae	1			1	1				1												4	6
/Orthocladiinae	1	3	4	3	1	3	2	1	1	3	1	8		1		1		1		3	37	4
/Tanypodinae	7	1	10				4	1	5	2	2					2					34	4
Chrysomelidae																				2	2	2
Cladocera					2						1										3	
Coenagrionidae			1																		1	2
Conoesucidae		6		10										10		1		6			33	7
Copepoda									1								1				2	
Corbiculidae/Sphaeriidae											1	1		1							3	5
Cordulephyidae									3				1	10							14	
Corixidae			10	4	10		10		10		10		10		5		10	3	10		92	2
Corophiidae										9											9	4
Corydalidae		7		4		10	1	9				1				2		1			35	7
Culicidae																	2				2	1
Curculionidae																				1	1	2
Decapoda larvae			10																		10	
Diphlebiidae														1							1	6
Diptera																			1		1	3

Continued…

Appendix 10. Continued

Order or Family	W1		W2		W3		W4		W5		W6		W7		W8		W9		W10		Total	Signal2
	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle		
Dixidae	9																				9	7
Dolichopodidae												2	1			4		2			9	3
Dugesiidae																			1		1	2
Dytiscidae	3		4		4		2		4		5		4		3				1		30	2
Ecnomidae												1		1		1					3	4
Elmidae	3	10	1	10		10	10	5	10	10	3	10	1	6	2	5	2	5		5	108	7
Empididae		1								2			1						2		6	5
Entomobryidae													1								1	
Gelastocoridae															1						1	5
Gerridae	1				1				4										10		16	4
Glossiphoniidae			1																		1	1
Glossosomatidae		5		1																	6	9
Gomphidae	1	2		5	9	2	10	1	3	7	10	10	1	2		2					65	5
Gordiidae	1	2																			3	5
Gripopterygiidae	5	10				3		7		1		1						3			30	8
Hebridae													1								1	3
Helicopsychidae			1			2	4	2	2	4	1	1									17	8
Hemicorduliidae	1					6			1			10		4							22	5
Hydracarina	10	10	10	8	1	8	2	6	9	2		3		2	2	1	8	2	4		88	6
Hydraenidae																	2				2	3
Hydrobiosidae		5				6		4		1		7		3							26	8
Hydrophilidae	10	1	1		10		2		6	1	2		4		1		5		9		52	2
Hydropsychidae		10	1	10	1	10	1	10		10		10		10	1	9				2	85	6
Hydroptilidae				1					2												3	4
Hypogastruridae			1	1					1								10	1	2	5	21	
Isostictidae			6	1	4		5		10		2				1						29	3
Leptoceridae	10	1	10	2	10	10	10	10	10	10	10	10	10	3	10	10	1	10	4	10	161	6
Leptophlebiidae	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10		10	8	10	188	8
Libellulidae			1	5	1		6	5		9	2		4		4			5	2	4	48	4
Nemertea										1											1	3
Nereididae							1														1	

Continued…

Appendix 10. Continued

Order or Family	W1		W2		W3		W4		W5		W6		W7		W8		W9		W10		Total	Signal2
	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle		
Noteridae									1	1			1		2						5	4
Notonectidae	1		7		2		2		10		1		5				2				30	1
Odontoceridae		1			2		1		1				1								6	7
Oligochaeta	9	5	5	10	1	1	10	2	2	8	2	5	1	1	3		10	3	3	1	82	2
Oniscigastridae	1																				1	8
Osmylidae																	1				1	7
Ostracoda			2				3		1					1			1				8	
Philopotamidae		2		4		10	1	10		10		10		10	1	10		1		1	70	8
Philorheithridae												1									1	8
Physidae			5	1			5	1	2	1	2	2	5	2	10		2	3	3	2	46	1
Planorbidae																	2				2	2
Protoneuridae			4																		4	4
Psephenidae	3	10	1	10	1	10	10	10	1	10	1	10		10	2	10		10	1	9	119	6
Pyralidae																			1		1	3
Scirtidae									1				1				10	1			13	6
Sialidae			1				1	1							1				1		5	5
Simuliidae		5								1		1						8			15	5
Stratiomyidae	1														1		2				4	2
Synlestidae	10		2				1														13	7
Synthemistidae			2		3								1								6	2
Tabanidae		1																1			2	3
Telephlebiidae	2	10	1	2		1	1								1						18	9
Tipulidae		1											1		2		5		1		10	5
Veliidae	1		6						2		1		4		10		1	2	1		28	3

Appendix 11. Summary of AusRivAS Bands for NSW a) Spring edge b) Spring riffle. AusRivAS Band derived from OE50 - based on the number of observed vs. expected macroinvertebrate taxa that occur in more than 50% of reference groups.

Band Label	Upper Limit		Band Name	Band Description
	a) Edge	b) Riffle		
Band X	Inf	Inf	Greater diversity than reference	More taxa found than expected. Potential biodiversity hot-spot. Possible mild organic enrichment.
Band A	1.16	1.18	Reference condition.	Most/all of the expected families found. Water quality and/or habitat condition roughly equivalent to reference sites. Impact on water quality and habitat condition does not result in a loss of macroinvertebrate diversity.
Band B	0.83	0.8	Significantly impaired.	Fewer families than expected. Potential impact either on water quality or habitat quality or both resulting in loss of taxa.
Band C	0.51	0.43	Severely impaired.	Many fewer families than expected. Loss of macroinvertebrate biodiversity due to substantial impacts on water and/or habitat quality.
Band D	0.19	0.06	Extremely impaired.	Few of the expected families remain. Extremely poor water and/or habitat quality. Highly degraded.