Shoalhaven Environmental Flows Knowledge Review

Determining and managing environmental flows
for the Shoalhaven River
Report 1

NSW Government
DEPARTMENT OF NATURAL RESOURCES

Water for Life
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Shoalhaven River

Water Supply Transfers and Environmental Flows

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Determining and managing environmental flows for the Shoalhaven River

Report 1 - Environmental Flows Knowledge Review

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"Riffles" are shallow areas of a river or stream where water flows rapidly over a gravel or rocky bed. They are very important in river ecology, adding oxygen to the water as it is churned and providing habitat for macroinvertebrates, which are small animals without backbones that are large enough to be visible with the naked eye. Examples include most aquatic insects, snails and crayfish.

The habitat value of riffles is an important consideration when developing an environmental flow regime, as is the need to provide sufficient flow over riffles to facilitate the passage of fish and other aquatic animals. The riffle in this photograph is one of 17 major riffles located in the freshwater river reach downstream of Tallowa Dam.

Photograph Source: Ivars Reinfelds, NSW Department of Natural Resources.

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Executive summary

A new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam

Water is required for human needs and to sustain the natural environment. However, the demands on water resources in many parts of Australia have reached a critical point where there is conflict between human uses and the maintenance of healthy ecosystems. Significant water reforms at a National and State level commencing in 1994 have addressed this problem by introducing the requirement for water to be provided for the environment. This water for the environment is widely described as ‘environmental flows’.

Through the Council of Australian Governments (COAG), agreement was reached in 1994 on an Australia-wide strategic framework to achieve an efficient and sustainable water industry. Critical environmental issues are identified in the COAG Water Reform Framework, including the allocation of water for the environment. In response to the COAG Framework, the NSW Government has been implementing its own water reform program since 1995, culminating in the *NSW Water Management Act 2000*. The Act states that management plans are to commit water as ‘planned environmental water’, and this provides the legislative basis for environmental flows in NSW.

Tallowa Dam is located on the Shoalhaven River on the NSW South Coast, and is managed by the Sydney Catchment Authority (SCA). The dam was constructed in the mid 1970’s to supply drinking water to the greater Sydney region and to generate hydro-electric power. The supply of drinking water to the greater Sydney region is achieved through the transfer of water from Tallowa Dam to the Hawkesbury-Nepean River system. To date, water has been transferred only during three periods of drought.

A provisional environmental flow release is in place for the Shoalhaven River downstream of Tallowa Dam. However, both the Healthy Rivers Commission Independent Inquiry into the Shoalhaven River System and the Hawkesbury-Nepean River Management Forum have highlighted shortcomings with this environmental flow. The Hawkesbury-Nepean River Management Forum recommended that the provisional environmental flow be replaced, and that a new regime of environmental flows be confirmed by a range of assessments of the lower Shoalhaven River, its catchment and the relationships to water management planning for Sydney.

In October 2004 the NSW Government released the Metropolitan Water Plan. This plan outlined the Government’s proposed approach to addressing the water supply needs of the greater Sydney area, and incorporated the Government’s response to the recommendations of the Hawkesbury-Nepean River Management Forum on environmental flows. For the Shoalhaven, the 2004 proposal sought to increase the total amount of water available for transfer to Sydney, improve the overall health of the Shoalhaven River, and secure local water supplies. The proposal for meeting these objectives involved increasing the capacity of Tallowa Dam, increasing the volume of water that could be transferred and implementing a new environmental flow regime.

After the release of the 2004 Metropolitan Water Plan, the NSW Department of Natural Resources (DNR) initiated the development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam.

In December 2005, the Government engaged independent experts to review the proposed approach to securing Sydney's water supplies. As a result of the review the Government has introduced new more sustainable and cost effective initiatives to secure Sydney's water supplies, both for drought and for the long term. The Government's new approach is described in the 2006 Metropolitan Water Plan, which is available at www.waterforlife.nsw.gov.au

For the Shoalhaven, the Government has announced that it will not proceed with raising Tallowa Dam wall. However, SCA is investigating changed pumping rules for the Shoalhaven system that would optimise the way the system is used, while minimising the impacts on river health and ensuring a secure water supply for Nowra and other South Coast communities. DNR's current process for the development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam is continuing, with a view to having a recommended regime ready for Government consideration at the end of the year.

The development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam involves the following steps:

1. *Knowledge review* - Compilation and analysis of existing knowledge to provide an understanding of the ecological and physical attributes of the Shoalhaven River downstream of Tallowa Dam, identify the known effects of the dam and its operation on those attributes and reveal information gaps.
2. *Investigations* - Conduct of a range of investigations to address information gaps and provide specific information on environmental flow requirements.
3. *Values and uses assessment and community comment* - Identification of the water and river uses and values that are important to the community, and community comment on options for environmental flows for the Shoalhaven River downstream of Tallowa Dam.
4. *Determination of recommended environmental flow regime* - Process to integrate the results of the above steps, and from this develop a recommended environmental flow regime for Government consideration.

This report presents the conclusions of step 1, the 'knowledge review'. From the conclusions of the knowledge review and the advice of specialists in NSW Government agencies, the Department of Natural Resources has initiated a range of ecological and physical investigations to examine the river environment and river flow processes. Social, economic, and cultural heritage investigations have also been initiated.

For further information on the process for the development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam, please refer to Chapter 1 of this report and the other Shoalhaven River environmental flows information resources produced by the NSW Government.

Conclusions of the knowledge review

The conclusions of the knowledge review are summarised below, including the knowledge gaps that have been identified. For further information please refer to Chapters 2, 3 and 4 of this report.

In carrying out the knowledge review, DNR examined the results and recommendations of relevant key studies and sought advice from the Cooperative Research Centre (CRC) for Freshwater Ecology and specialists in NSW Government agencies.

Fluvial geomorphology

Geomorphological setting

Fluvial geomorphology is the study of river processes and form. Geomorphological studies of the Shoalhaven River have identified three distinct river reaches downstream of Tallowa Dam:

- confined valley with discontinuous floodplain between Tallowa Dam and Burrier (freshwater river reach);
- bedrock controlled tidal zone between Burrier and Nowra (upper estuary); and
- tidal coastal plain between Nowra and the ocean (lower estuary).

Conceptual models developed for the three reaches illustrate the key characteristics of each reach and introduce the potential impacts of Tallowa Dam. The conceptual models are presented in Chapter 2 of this report.

Sediment transport

A lack of significant sediment cover over the steeply sloping continental landscape of southern NSW has resulted in a comparatively low rate of sediment supply to the lower Shoalhaven River. Additionally, Tallowa Dam now acts as a sediment trap. However, the sediment loading of the Shoalhaven River appears to increase downstream of the confluence of Yalwal Creek and the Shoalhaven River. Yalwal Creek joins the Shoalhaven River in the freshwater river reach between Tallowa Dam and Burrier.

Tallowa Dam is known to have had an impact on sediment supply to the lower Shoalhaven River, but the extent of this impact is not known. More information is required on sediment transport processes, the impacts of Tallowa Dam on these processes, and the role of environmental flows in these processes. This information will help to identify how sediment supply and channel processes will respond to a new environmental flow regime, with channel geomorphology having an important role in determining habitat availability for various river organisms.

Acid sulfate soils

Acid sulfate soils are found on the Shoalhaven floodplain. However, the floodplain reach of the river is dominated by tidal processes, and flood mitigation works on the floodplain mean that only the largest freshwater river floods can now reach the acid sulfate soils. Because of this, changes to the hydrology of the Shoalhaven River as a result of Tallowa Dam and associated transfers are unlikely to be a driving factor for acid production on the floodplain.

Hydrology

Hydrology is the study of the properties, distribution and circulation of water on the surface of the land, underground, and in the atmosphere.

Water extractions

Shoalhaven City Council extracts water from the Shoalhaven River at Burrier, and the SCA can transfer water from Tallowa Dam to the Hawkesbury-Nepean River System.

There are also a number of other licensed water users downstream of Tallowa Dam. The amount of water used is small compared to Shoalhaven City Council's extractions and the SCA's transfers. In addition, landowners with a direct river frontage are permitted to extract water for domestic purposes and stock watering. As this water is extracted under one of three types of Basic Landholder Rights in the *Water Management Act 2000*, there is no record of the amount of water extracted. The exact volume of water extracted for Basic Landholder Rights downstream of Tallowa Dam should be determined as these extractions affect the actual amount of water received by the environment.

Discharges

As well as the range of extractions, there are discharges of wastewater into the Shoalhaven River estuary from several sources. The amount of water discharged is small compared to the overall amount of water extracted.

Impact of water transfers on river flow

Since 1980, water has been transferred from Tallowa Dam to the Hawkesbury-Nepean River System during three periods of drought. This has had a negative impact on low flows in the Shoalhaven River downstream of Tallowa Dam. Overall, the water transfers have had little impact on moderate and high flows along the Shoalhaven River.

Flow modelling

Most of the flow modelling for the Shoalhaven River downstream of Tallowa Dam has been based on monthly flow data. However, the Shoalhaven River experiences extreme variability in flow, with flows often changing from one day to the next. This means that models based on daily or even hourly flow data are required to facilitate an accurate determination of the amount of water required to provide suitable species habitat and a better understanding of the aspects of the flow that are important for the health and reproduction of various species.

Groundwater

The Shoalhaven River catchment is not noted for its groundwater resources, however there is some concern that extraction of groundwater from the headwaters of the Kangaroo River may impact on base flows in the river system.

The Shoalhaven River floodplain has relatively high water tables, with ground water being brackish to saline. Groundwater flows in the floodplain are unknown.

More information on groundwater is desirable as the interaction of groundwater with the river can affect river hydrology and ecology.

Water quality

Monitoring and analysis of water quality

Current monitoring and analysis of water quality downstream of Tallowa Dam is limited in its ability to detect the current extent of dam impacts or the future effects of a new environmental flow regime. The monitoring and analysis is inadequate in terms of the number of monitoring sites and their location, the variables that are measured, and the study design. There is also a lack of analysis of water quality data in terms of its relationship to ecology, and more focussed monitoring is needed of variables and indicators relevant to ecological outcomes.

Impacts of dam stratification

Despite the inadequacy of current monitoring and analysis of water quality, it is clear the river downstream of the dam has been negatively impacted by dam releases that have been cold and low in quality. Tallowa Dam has had the effect of suppressing water temperature in summer and spring, and elevating water temperature in winter. The temperature suppression in summer and spring has been a result of the release of cold water from outlets in the dam wall 20 metres below the spillway crest when the dam is stratified. In a stratified water body, distinct layers of different temperature, density and water quality develop at various depths with a restriction of mixing throughout the water column, so that a less-dense surface layer generally overlays bottom waters that are cold, dense, low in oxygen and low in quality. Temperature is the major contributing factor, with stratification generally occurring as surface waters warm in summer and spring.

At Grassy Gully, 20 km downstream of Tallowa Dam, the suppressed temperature recovers to approximately the same temperature as the Shoalhaven River above Lake Yarrunga. However, it has not been possible to determine exactly how far downstream from the dam the cold water pollution has been extending as there are currently no other monitoring sites between Tallowa Dam and Grassy Gully.

Stratification of the water column in Tallowa Dam can also lead to the release of iron, manganese and aluminium from bottom sediments into the water column which, if discharged from the dam, can lead to similarly increased concentrations of these elements in downstream waters. Iron precipitate and iron-oxidising bacteria have been particularly evident in the Shoalhaven River immediately downstream of the dam, and monitoring data indicates that elevated concentrations of iron have been present. The implications of this are the direct loss of both native plants and animals, or the loss or simplification of habitat.

As a pilot measure to address stratification, the SCA recently installed a compressor and aeration system in Lake Yarrunga to mix warmer surface water with the cooler deeper water. The SCA will study the downstream environment to monitor changes resulting from the system. A multilevel offtake, which would allow water to be released from different levels in the lake, is also being considered.

Stratification of natural pools

As well as occurring in dams, stratification can occur in the deep pools that occur in river systems. Stratification of the deep pools in the Shoalhaven River downstream of Tallowa Dam can occur naturally. However, the frequency, duration and magnitude of stratification events could be exacerbated by prolonged low flows caused by transfers from Tallowa Dam to the Hawkesbury-Nepean River System. Stratification can have significant impacts on both water quality and pool-dependent plants and animals. High freshwater short term events in river systems, in particular flood flows, help to mitigate the effects of stratification by flushing out deep pools with fresh water.

Estuary salinity

There is currently uncertainty in regard to the salinity regime in the Shoalhaven River estuary and the impact of freshwater extractions on that regime. An examination of Shoalhaven River estuary salinity in 2003 concluded that the low salinity zone of the estuary had been greatly compressed, and water extractions were identified as a potential contributor to this compression. Different conclusions were drawn in hydrological investigations completed in 1996 for Shoalhaven City Council. These investigations found that the Shoalhaven River estuary was dominated by tidal processes, and that high freshwater short-term events only had a short temporary effect on the salinity regime in a small section of the upper estuary.

In addition to the possible compression of the low salinity zone of the estuary, freshwater extractions could be changing the variability of the salinity regime or reducing the volume or frequency of flushing flows. The impact of freshwater extractions on salinity variability may be ecologically significant for the Shoalhaven.

Further investigation is needed to resolve uncertainty in regard to the salinity regime in the Shoalhaven River estuary, the impact of freshwater extractions on that regime and the effects of an environmental flow on that regime. This should involve detailed numerical modelling of the estuary, carried out in association with examining the inflow/salinity responses of estuarine plants and animals that are sensitive to changes in salinity.

Other water quality issues

Another potential water quality problem is the risk of the downstream release of the high levels of cyanobacteria (blue-green algae) that have been recorded in the Kangaroo Arm of Lake Yarrunga. However, this risk has already been addressed in SCA's Water Management Licence.

Further investigation is needed into the impact of flows and particularly flushing flows on water quality and the relationship between flow and the transport of organic matter and nutrients down the river.

Ecology

Fish

The best biological data available for the Shoalhaven River downstream of Tallowa Dam is in regard to fish due to the presence of numerous species of commercial and recreational interest. The Shoalhaven River has special significance for fish conservation because it has provided permanent habitat for the Australian grayling, which is listed as vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and protected in New South Wales and Victoria.

The distribution of many native fish in the Shoalhaven River has been affected by the physical presence of Tallowa Dam, which acts as a barrier to fish migration. Native fish species can also be affected by the associated effects that dam operations have on flow, water quality and physical habitat; with some freshwater species found to be sensitive to changes in flow. A relationship between commercial fish catches and Shoalhaven River flow has been found, however there remains uncertainty around which aspects of the flow regime influenced each species. The SCA is proposing to construct a fish passageway to address the barrier to fish migration currently presented by the Tallowa Dam wall.

The Australian bass has been a focus of interest in the Shoalhaven River because it is a top predator in the food web of the river system and an iconic species in terms of recreational fishing. This is the species on which the original provisional environmental flow recommendations were based, however this may need to be reassessed because this flow has been observed to be insufficient to cover riffles in some sections of the river. 'Riffles' are the shallow areas of the river where water flows rapidly over a gravel or rocky bed, and there is a need to provide sufficient flow over them to facilitate the passage of fish.

Macroinvertebrates

Macroinvertebrates are animals without backbones that are large enough to be visible with the naked eye, with examples including most aquatic insects, snails and crayfish. Some information is available in regard to the distribution, health and habitat requirements of macroinvertebrate communities downstream of Tallowa Dam. Based on the assemblages recorded, there appear to be fewer macroinvertebrate species in the freshwater reach downstream of Tallowa Dam than would be expected. Further downstream in the Shoalhaven River estuary, observed variation in the patterns of distribution and abundance of macroinvertebrates was found to correlate strongly with variations in salinity.

Most of the macroinvertebrate sampling conducted to date has been undertaken in the upper part of the catchment, with only limited sampling below the dam. Previous sampling has not been designed to detect changes along the river due to the presence of the dam, and as a result little is known about the effect of the dam or water transfers on macroinvertebrate communities and how far downstream these effects may extend. There has also been limited use of macroinvertebrate data for assessing ecosystem condition, as so far most analysis has focussed on describing community composition, distribution and abundance.

Other river dependant fauna

Limited information is available on other river dependent fauna such as platypus, turtles, water rats and frogs. More information is needed on the current distribution, abundance, condition, habitat preferences and flow responses of such species.

Fauna habitat

The current provisional environmental flow release has been observed to be insufficient to cover riffles in some sections of the Shoalhaven River downstream of Tallowa Dam. The reduction of flows over riffles is a key issue, as it can result in decreased habitat connectivity for mobile aquatic fauna along the freshwater river reach and at the interface between the freshwater reach and the estuary. The species potentially adversely affected include fish, macroinvertebrates, platypus and turtles.

Additionally, altered river hydrology due to the presence and operation of Tallowa Dam could lead to modified habitat dynamics, for example the expansion or contraction of particular habitats and the increased stagnation of pools from reduced flushing flows. This would contribute to a loss of diversity in some faunal groups and the alteration of the structure of aquatic communities.

Aquatic macrophytes and riparian vegetation

Aquatic macrophytes are rooted and floating aquatic plants that are large enough to be visible with the naked eye. In the estuarine section of the river, changes to aquatic macrophytes and riparian (riverbank) vegetation are believed to be a response to increased salinisation of the estuary under low flow conditions. The setback of riparian vegetation immediately below the dam is probably in response to high flow spills over the dam wall. Further down the river, riparian vegetation is encroaching on the channel as a result of reduced flow in drought conditions. Introduced species and degradation of the riparian zone by cattle are problems in the lower reaches of the river.

Further investigation is needed to determine the extent of aquatic macrophytes, the presence of exotic species, and the response of aquatic macrophytes to a new environmental flow regime.

Wetlands and waterbirds

There is little information available on waterbirds, even though wetlands of the Shoalhaven River estuary are classified as one of the three most important waterbird habitats in NSW, and the Directory of Important Wetlands in Australia lists 78% of the wetlands in the Shoalhaven catchment as important. Existing knowledge of wetland condition is also poor. Most of the estuary wetlands have been adversely affected by reduced flooding as a result of flood mitigation and drainage works on the Shoalhaven River floodplain.

Because of the flood mitigation and drainage works, environmental flows are unlikely to be able to assist any of the riverine or floodplain wetlands. However, further investigation is needed.

Flow-ecology relationships

The relationship between the degree of flow modification and ecological or geomorphological change is not simple. A direct relationship between flow modification and ecological and geomorphological change might be expected, where a small flow modification results in small ecological and geomorphological changes and a large flow modification results in large changes. However, this is not always the case, as severe ecological and geomorphological changes can occur in response to even small alterations to flow.

Studies of the Shoalhaven River downstream of Tallowa Dam conducted so far have not been designed to detect ecological responses to changes in flow brought about by dam operation. In the absence of studies directly examining the relationship between flow modification and ecological and geomorphological change, it can be difficult to determine the effect of a new environmental flow as rivers are complex systems and are influenced by many interacting biological and human factors. The Multiple Levels and Lines of Evidence (MLLE) approach is proposed as a logical way of organising evidence to be able to infer cause and effect. In the MLLE framework:

- a *line of evidence* is a type of evidence, such as an ecosystem attribute (e.g. fish abundance), that is investigated in relation to a stressor or intervention; and
- a *level of evidence* is a strength-of-evidence value used to determine the case for inferring that a given human activity causes a given ecological or geomorphological change.

The CRC for Freshwater Ecology assessed the available literature using the MLLE approach to assist in the determination of environmental flows for the Shoalhaven River downstream of Tallowa Dam. An initial literature review identified seven lines of evidence which were used in the assessment, being fish, macroinvertebrates, periphyton/algae , water quality, geomorphology, riparian vegetation and platypus (periphyton are algae that are attached to rocks or other aquatic substrates). A search of Australian and international scientific literature was conducted, resulting in 39 scientific papers being entered into specially developed MLLE software, which was then used to test questions about the downstream ecological impacts of:

- the temperature of water released from Tallowa Dam;
- a reduction in flow variability; and
- a reduction in flow volume.

Only questions concerning ecological impacts were tested, as the MLLE assessment found that none of the studies assessing geomorphology could be used. This may be because, as a geological process, geomorphology generally takes longer than biological processes to respond to change, and is therefore difficult to study rigorously. While geomorphology may be an important component of ecosystem function, the length of time needed for its study means that it may be more feasible to examine other equally important lines of evidence when developing an environmental flow regime.

The results of the MLLE assessment were:
1. Few scientific papers were found concerning the effects of a reduction in flow variability, and these papers offered little support for determining if a reduction in flow variability has a negative ecological effect.
2. Many papers were found that demonstrated an ecological response to changes in flow volume. The strongest lines of evidence were fish and macroinvertebrates.
3. Some papers were found that were relevant to the question of whether temperature changes downstream of dams have an effect on stream ecology. However, the evidence provided by these was not strong.

The MLLE assessment suggests that investigating fish and macroinvertebrates would provide ecological information about the impact of flow volume in which considerable confidence could be placed.

Adaptive management

A considerable amount of knowledge is available to assist the determination of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam. In addition, further information will be revealed by current investigations. However, because the science of environmental flows is relatively new, the knowledge base is incomplete. The Precautionary Principle advises that lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation, meaning that a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam should be implemented because the available knowledge clearly shows that improvements can be made to the current situation.

An adaptive management approach is particularly useful in the implementation of the Precautionary Principle, as full scientific certainty about management measures is not required before implementation. The adaptive management approach involves implementing such measures as part of rigorously planned and controlled programs, with the periodic review of scientific information that has been specifically collated to enable environmental flow decision-makers to evaluate the effectiveness of previous decisions and 'adapt' future decisions. The best outcomes are achieved when the process is set up to allow the people who generate the scientific information to have independence from the decision-makers. This reduces the risk of inadvertent bias in the decision-making and helps to keep the focus on the outcomes of the science rather than on how the science was done.

Maintaining or improving the health of the ecology and ecological processes of the Shoalhaven River downstream of Tallowa Dam is the main purpose of implementing a new environmental flow regime. As a result, decisions need to be made in regard to the species, ecological communities or ecological processes that will be targeted for assessment to determine if key ecological objectives are being met. Decisions about what will be targeted should be made at the outset, but can be modified later if necessary through the adaptive management process. To make these decisions, the following questions need to be answered:
1. What species, ecological communities or ecological processes will be targeted, and what is their relationship to the environmental flow regime?
2. What are the key ecological objectives for each?
3. What is the current distribution and abundance of target species, the current health of target ecological communities and the current state of ecological processes?
4. What key information on the ecology of species and their habitat requirements still needs to be collected to inform decisions in regard to a new environmental flow regime?

5. What environmental flow regime will achieve the key ecological objectives for the target species, ecological communities and ecological processes?

In the adaptive management framework, assessment is required to determine if the key ecological objectives are being met. It may not be practical or possible or indeed necessary to measure all of the ecological processes or organisms for which there are key ecological objectives. Indicator species or groups can instead be utilised, where a smaller subset of all of the species and groups is identified and used to indicate the condition of the overall river environment and the status of other species and groups in the river environment. Some considerations for the choice of indicators include:

- select indicators that are indicative of the wider range of ecological processes and broader ecological health that is being assessed;
- select indicators that are responsive to the proposed management interventions and that will respond in appropriate timescales;
- select indicators that are relatively easy to measure; and
- consider indicators that also have important social and/or economic meaning.

The Multiple Lines and Levels of Evidence (MLLE) assessment identified that for determining effects related to flow volume, most support in the literature is available for fish and macroinvertebrates. Both of these groups would make suitable indicators according to the above considerations. Fish are a top-level predator and contribute to important ecosystem processes, they respond to flow (although on longer timeframes of 3-5 years), they are relatively easy to measure and have both social and economic importance. Macroinvertebrates are also indicative of a range of processes, will respond to changes in flow volume (and on much shorter timeframes than fish) and are also easy to measure, although they are generally not considered socially or economically important.

1. Introduction

1.1 The background to environmental flows

Water is required for human needs and to sustain the natural environment. Water is essential for our towns and cities and for irrigating our farmland, and also provides us with economic and social benefits through supporting commerce and recreation. Water is also essential for the health of the natural ecosystems in our rivers, streams and wetlands. A realisation that the human use demands on water resources in many parts of Australia were causing the decline of the natural environment has contributed to the significant water reforms that have occurred at a National and State level. These reforms have recognised that the environment needs an appropriate share of water to protect the fundamental health of natural ecosystems, with this share of water widely described as 'environmental flows'. (DLWC 1998).

The water reforms commenced in 1994, when the Council of Australian Governments (COAG) consisting of the Prime Minister, Premiers, Chief Ministers and the President of the Australian Local Government Association agreed to implement a strategic framework to achieve an efficient and sustainable water industry. The Framework required the States to undertake a wide range of legislative reforms in relation to water, including ensuring the provision of water to meet environmental needs. (DEH 2004).

The NSW Government subsequently launched its water policy reform agenda in 1995, with a program that included improved environmental flows in two river valleys where there are internationally recognised wetland areas. In 1997, the reform agenda was extended to encompass additional reforms including the development of environmental flows for all of the regulated river systems in NSW. (DLWC 1998).

In 1999, the NSW Government worked closely with the community to develop Interim Environmental Objectives for Water Quality and River Flow for NSW waters. The Water Quality Objectives are based on measurable environmental values that provide the appropriate water quality for environmental and human-related needs. The River Flow Objectives aim to improve and maintain river health by recognising the importance of natural river flow patterns in managing riverine water sources. (NSW Government 2002).

The NSW water reforms culminated in the NSW *Water Management Act 2000*, which has represented the biggest overhaul of water legislation for the State since early last century (DLWC 2001a). The principal object of the Act is to provide for the sustainable and integrated management of the State's waters for the benefit of both current and future generations. The Act states that management plans are to commit water as 'planned environmental water', and this provides the legislative basis for environmental flows in NSW.

The State Water Management Outcomes Plan was established in 2002 under the *Water Management Act 2000* to set out the over-arching policy context, targets and strategic outcomes for the development, conservation, management and control of the State's water sources. In particular, the State Water Management Outcomes Plan seeks to ensure that the NSW Government's Interim Environmental Objectives for Water Quality and River Flow are explicitly addressed in future water resource management and action.

1.2 Environmental flows in the Shoalhaven River

Tallowa Dam is a water storage located on the Shoalhaven River on the NSW South Coast, and was constructed in the mid 1970's to supply drinking water to the greater Sydney region and to generate hydro-electric power. Tallowa Dam is managed by the Sydney Catchment Authority (SCA). The supply of drinking water to the greater Sydney region is achieved through the transfer of water from Tallowa Dam to the Hawkesbury-Nepean River system. To date, water has been transferred only during three periods of drought. (SCA 2002).

Following the commencement of the NSW water reforms, provisional environmental flow releases were introduced in the Hawkesbury-Nepean, Shoalhaven and Woronora River Systems (HNRMF 2004). The Background Report *Issues relating to the determination of environmental flows for the Shoalhaven River* was also prepared in 1999 by Macquarie University for the NSW Department of Land and Water Conservation (Norman and Turner 1999).

The provisional environmental flow for the Shoalhaven River downstream of Tallowa Dam involves the release of up to 90 ML/day (megalitres per day), based on studies undertaken in 1996 for Shoalhaven City Council (Dames and Moore 1996, The Ecology Lab 1996, HRC 1999). Flows of up to 180 ML/day are actually released, with the flow between 90 and 180 ML/day available for extraction by Shoalhaven City Council further downstream at Burrier. Sydney Water agreed to this environmental flow release as an interim measure. The management responsibility for Tallowa Dam was transferred from Sydney Water to the SCA following the establishment of the SCA in 1999, and the release of up to 90 ML/day was subsequently specified as a 'provisional environmental flow release' in the SCA's Water Management Licence in 2001 (HNRMF 2004, DLWC 2001b).

Both the Healthy Rivers Commission Independent Inquiry into the Shoalhaven River System and the Hawkesbury-Nepean River Management Forum have highlighted shortcomings with the provisional environmental flow release. For example, it does not meet the requirements of an effective regime of environmental flows because it does not adequately mimic the natural variability of flow which is essential to ecological processes (HRC 1999, HNRMF 2004). The current environmental flow releases have natural variability when Tallowa Dam inflows are between 0 and 90 ML/day, and there is also natural variability when the inflows are high enough for the dam to spill. However, there is no natural variability when inflows are between 90 ML/day and the higher flows that make the dam spill. This is because the environmental flow release remains at a constant 90 ML/day.

The Healthy Rivers Commission (HRC) was an independent Commission of Inquiry established in 1996 as part of the NSW water reforms, for the purpose of making recommendations to the Government on appropriate long-term approaches and strategies to achieve environmental, social and economic objectives for specified river systems. The HRC Independent Inquiry into the Hawkesbury-Nepean River System was completed in 1998, and the HRC Independent Inquiry into the Shoalhaven River System was completed in 1999. The HRC was abolished in 2003, when the NSW *Natural Resources Commission Act 2003* established the Natural Resources Commission (NRC) as a single independent commission replacing ten former Government advisory bodies that had dealt with various aspects of natural resources management.

In February 2000, the NSW Government responded to the HRC Final Report on the Hawkesbury-Nepean River System, approving the development of a Statement of Joint Intent to record the commitments of State agencies and relevant Councils to implement the HRC recommendations that had been endorsed by Government (NSW Government 2001). The NSW Government also issued a

Statement of Intent for the Shoalhaven River System in response to the HRC Final Report on the Shoalhaven River System (NSW Government undated).

The Statement of Joint Intent for the Hawkesbury-Nepean River System, issued in March 2001, included a strategy stating that 'A Hawkesbury-Nepean River Management Forum is to be established to make recommendations to the Ministers for Land and Water Conservation and the Environment on environmental flow provisions for inclusion in the water management licence of the Sydney Catchment Authority…'. The Forum was also tasked with examining transfers between the Shoalhaven and Hawkesbury-Nepean River Systems, with this examination recognising the future potential need for increased transfers due to increased demand from population growth in Sydney. (NSW Government 2001, HNRMF 2004).

The Hawkesbury-Nepean River Management Forum was established in April 2001, and an Independent Expert Panel on Environmental Flows for the Hawkesbury-Nepean, Shoalhaven and Woronora catchments (IEP) was established in August 2001 to provide comprehensive scientific advice to support the Forum (HNRMF 2004). The Forum published its Final Report in March 2004, and recommended that:

- the existing environmental flow release for the Shoalhaven River downstream of Tallowa Dam be replaced with one that better mimics natural flows; and
- a new regime of environmental flows needed to be confirmed by ecological, economic, social and engineering assessments of the lower Shoalhaven River, its catchment and the relationships to water management planning for Sydney.

In October 2004 the NSW Government released the Metropolitan Water Plan, which identified the proposed approach to addressing the water supply needs of the greater Sydney area and incorporated the Government's response to the recommendations of the Hawkesbury-Nepean River Management Forum on environmental flows (DIPNR 2004a, DIPNR 2004b). For the Shoalhaven, the 2004 proposal sought to increase the total amount of water available to Sydney, improve overall river health in the Shoalhaven, and secure local water supplies (NSW Government 2006a). The proposal for meeting these objectives involved:

- increasing the capacity of Tallowa Dam through the installation of radial gates on the existing dam crest;
- increasing the volumes that could be transferred each day by replacing the existing transfer mechanism with a new large diameter tunnel; and
- implementing a new environmental flow regime governing the timing, quantity and quality of releases from Tallowa Dam.

After the release of the 2004 Metropolitan Water Plan, the NSW Department of Natural Resources (DNR) initiated the development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam.

In December 2005, the Government engaged independent experts to review the proposed approach to securing Sydney's water supplies and to advise on the effectiveness of the range of current and proposed measures to ensure a balance between supply and demand. As a result of the review the Government has introduced new initiatives that amount to a more sustainable and cost effective way to secure Sydney's water supplies, both for drought and the long term. The Government's new approach is described in the 2006 Metropolitan Water Plan, which is available at www.waterforlife.nsw.gov.au (NSW Government 2006a, NSW Government 2006b).

For the Shoalhaven, the Government has announced that it will not proceed with raising Tallowa Dam wall. However, the SCA is investigating changed pumping rules for the Shoalhaven system that would optimise the way the system is used, but minimise river health impacts and ensure security of supply for Nowra and other South Coast communities. DNR's current process for the development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam is continuing, with a view to having a recommended regime ready for Government consideration at the end of the year.

The new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam will be protected through the water sharing plan that is being prepared for the greater Sydney region. Water sharing plans are prepared under the *Water Management Act 2000* to define the water sharing arrangements between the environment and water users, and between different categories of water users. The water sharing plan for the greater Sydney region is expected to initially protect the current environmental flow release for the Shoalhaven River downstream of Tallowa Dam, and subsequently protect the new environmental flow regime when it has been decided.

1.3 Development of the new environmental flow regime

The development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam involves the following steps:

1. *Knowledge review* - Compilation and analysis of existing knowledge to provide an understanding of the ecological and physical attributes of the Shoalhaven River downstream of Tallowa Dam, identify the known effects of the dam and its operation on those attributes and reveal information gaps.
2. *Investigations* - Conduct of a range of investigations to address information gaps and provide specific information on environmental flow requirements.
3. *Values and uses assessment and community comment* - Identification of the water and river uses and values that are important to the community, and community comment on options for environmental flows for the Shoalhaven River downstream of Tallowa Dam.
4. *Determination of recommended environmental flow regime* - Process to integrate the results of the above steps, and from this develop a recommended environmental flow regime for Government consideration.

This report presents the outcomes of the 'knowledge review' step. From the conclusions of the knowledge review and the advice of specialists in NSW Government agencies, the Department of Natural Resources has initiated a range of ecological and physical investigations to examine the river environment and river flow processes. Social, economic, and cultural heritage investigations have also been initiated.

1.4 Information sources for the knowledge review

In carrying out the knowledge review, DNR examined the results and recommendations of key studies and sought advice from the Cooperative Research Centre (CRC) for Freshwater Ecology and specialists in NSW Government agencies.

A key reference source for information on the ecological and physical attributes of the Shoalhaven River downstream of Tallowa Dam has been the 1999 Macquarie University Background Report *Issues relating to the determination of environmental flows for the Shoalhaven River* (Norman and Turner 1999). Published and unpublished literature was reviewed in this Background Report to identify issues relevant to environmental flows for the Shoalhaven River and determine major information sources. The focus was primarily on biological and physical information, but descriptions of river use and management and a summary of community concerns and issues were also provided.

Since 1999, considerable development and understanding has occurred in the determination of environmental flows and new information has become available on the Shoalhaven River catchment. Recognising this, DNR engaged the CRC for Freshwater Ecology to conduct a literature review (Coysh *et al.* 2005) which had the specific objectives of:

- updating the 1999 Macquarie University Background Report (Norman and Turner 1999);
- identifying, compiling and analysing existing knowledge to provide an understanding of the biological, chemical, hydrological, geological and geomorphological attributes of the environment of the Shoalhaven River;
- characterising the known effects of Tallowa Dam and its operation on the physical and environmental condition of the Shoalhaven River; and
- developing a conceptual understanding of flow-ecology relationships in the Shoalhaven River and estuary.

In addition to the 1999 Macquarie University Background Report, other key references examined by the CRC for Freshwater Ecology and DNR include:

- Shoalhaven City Council Environmental Impact Statement (EIS) for Stage 2B of the Shoalhaven City Water Supply Augmentation (Dames and Moore 1996) and associated reports (Lawson and Treloar 1996, The Ecology Lab 1996);
- Healthy Rivers Commission *Independent Inquiry into the Shoalhaven River System* (HRC 1999);
- Hawkesbury-Nepean River Management Forum Final Report *Water and Sydney's future: Balancing the values of our rivers and economy* (HNRMF 2004);
- Reference documents used by the Hawkesbury-Nepean River Management Forum in compiling their Final Report on Water and Sydney's Future, including the documents prepared by the Independent Expert Panel (IEP) on Environmental Flows for the Hawkesbury-Nepean, Shoalhaven and Woronora Catchments; and
- Shoalhaven City Council *Shoalhaven River Estuary Data Compilation Study* (Umwelt 2005).

A detailed reference list can be found in Chapter 6 of this report.

1.5 Associated environmental issues

As well as making recommendations in regard to a new environmental flow regime, the investigations carried out by Macquarie University, the Healthy Rivers Commission, the Hawkesbury-Nepean River Management Forum and the CRC for Freshwater Ecology have identified other environmental issues associated with Tallowa Dam. The dam is currently acting as a barrier to fish species that need to migrate between fresh and salt water during their life cycle, for example the Australian bass. Additionally, because water is released from outlets 20 metres below the spillway crest, downstream discharges of water that is cold, low in oxygen and lower in quality have been released when the dam is stratified and this has posed a risk to fauna and flora. In a stratified dam, distinct layers of different temperature, density and water quality develop at various depths with a restriction of mixing throughout the water column.

As a pilot measure to address stratification, the SCA recently installed a compressor and aeration system in Lake Yarrunga to mix warmer surface water with the cooler deeper water. The SCA will study the downstream environment to monitor changes resulting from the system. A multilevel offtake, which would allow water to be released from different levels in the lake, is also being considered. The SCA is also proposing to construct a fish passageway to address the barrier to fish migration currently presented by the Tallowa Dam wall. (SCA 2005).

1.6 Environmental flows legislation and policy

Section 8 of the *Water Management Act 2000* states that management plans are to commit water as 'planned environmental water' and must contain provisions for the identification, establishment and maintenance of planned environmental water. These provisions are defined as 'environmental water rules'. Planned environmental water is defined as water that is committed for fundamental ecosystem health or other specified environmental purposes, either generally or at specified times or in specified circumstances, and that cannot to the extent committed be taken or used for any other purpose.

The State Water Management Outcomes Plan (SWMOP) established under Section 6 of the *Water Management Act 2000* sets out the policy context for the development of 'environmental water rules'. The SWMOP seeks to ensure that the NSW Government's Interim Environmental Objectives for Water Quality and River Flow are explicitly addressed in water resource management and action. The Interim Environmental Objectives identify the broad goals to achieve long-term river health, maintain biodiversity and secure sustainable water sources for communities and industries dependent on water of a certain quality. The Water Quality Objectives are based on measurable environmental values that provide the appropriate water quality for environmental and human-related needs, and the River Flow Objectives aim to improve and maintain river health by recognising the importance of natural river flow patterns in managing riverine water sources.

The Interim Environmental Objectives for River Flow are (EPA 1997, NSW Government 2002):

RFO 1	Protect natural water levels in river pools and wetlands during periods of no flow.
RFO 2	Protect natural low flows.
RFO 3	Protect or restore a portion of freshes and high flows.
RFO 4	Maintain wetland and floodplain inundation.
RFO 5	Mimic the natural frequency, duration and seasonal nature of drying periods in naturally temporary streams.
RFO 6	Maintain or mimic natural flow variability in all streams.
RFO 7	Maintain natural rates of change in water levels.
RFO 8	Manage groundwater for ecosystems.
RFO 9	Minimise the impact of in-stream structures.
RFO 10	Minimise effects of dams on water quality.
RFO 11	Ensure that the management of river flows provides the necessary means to address contingent environmental and water quality events.
RFO 12	Maintain or rehabilitate estuarine processes and habitats

The Interim Environmental Objectives for River Flow are reflected in the long term outcomes and 5-year management targets in the SWMOP. The long term outcomes for the environment are to:

- maintain or improve primary ecological production;
- improve degraded wetlands, and protect and restore those listed as wetlands of national or international significance; and
- protect and restore the diversity and abundance of native aquatic animals and plants.

The SWMOP 5-year management target directly relating to environmental flows is Target 4:

Target 4 - Environmental water rules and extraction limits established in regulated and unregulated rivers subject to a gazetted water sharing plan such that:

Target 4a - Wherever the frequency of "end of system" daily flows would be less than 60 percent of the predevelopment level without environmental water rules or extraction limits, the flows increased to 60 percent of predevelopment levels or increased by at least 10 percent of the predevelopment frequency.

Target 4b - Frequency of "end of system" daily very low flows (as defined by local field investigation) protected or restored to predevelopment levels to maintain or restore their critical ecological functions, drought refuges and habitat connectivity. In the absence of such local assessments, protection extended up to at least the predevelopment 95th percentile.

Target 4c - The channel capacity of all lower river and effluent creek systems used for the delivery of regulated water determined. Subject to reasonable socioeconomic impacts, limits on daily supply volumes established for effluent systems such that they do not exceed 80 percent of the channel capacity for more than 10 percent of days in each month of each year. Where daily supply volumes are currently substantially less than channel capacity, alternative limits established to reduce the impact of unseasonal flows arising from future access licence dealings.

Target 4d - A proportion of the natural drying phases reinstated in the core areas of terminal wetlands.

The protection of natural low flows (RFO 2, Target 4b), the protection or restoration of a portion of freshes and high flows (RFO 3, Target 4a) and maintaining or mimicking natural flow variability (RFO 6, Target 4) are identified as the three most critical aspects of a river flow regime (NSW Government 2002).

1.7 Contents of this report

This report presents the outcomes of the initial 'knowledge review' step of the process for the development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam. For information on the steps involved in the development of a new environmental flow regime refer to Section 1.3.

Chapter 2 provides an overview of the Shoalhaven River catchment, Tallowa Dam and its management and current environmental flow releases. **Conceptual models** are used to illustrate the key characteristics of the three river reaches downstream of Tallowa Dam and introduce the potential impacts of the dam.

Chapter 3 presents a **detailed review of the current knowledge relating to environmental flows** in the Shoalhaven River downstream of Tallowa Dam, drawing on the advice of the CRC for Freshwater Ecology and specialists in NSW Government agencies and DNR's examination of the results and recommendations of key studies.

Chapter 4 is a summary of the **conclusions** of this report.

Chapter 5 presents a **glossary of terms and acronyms** used in this report.

Chapter 6 lists the report **references**.

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2. Overview of the Shoalhaven River downstream of Tallowa Dam

This Chapter provides an overview of the Shoalhaven River catchment, Tallowa Dam and its management and current environmental flow releases. Conceptual models are used to illustrate the key characteristics of the three river reaches downstream of Tallowa Dam and introduce the potential impacts of the dam.

2.1 The Shoalhaven River catchment

The Shoalhaven River originates south-east of Canberra and west of Batemans Bay. It flows north for 170 km towards Braidwood before flowing eastwards towards the coast at Nowra where it opens to the sea at Crookhaven Heads. Historically, the Shoalhaven River's entrance to the ocean was further north at Shoalhaven Heads; however in 1822 the European settler Alexander Berry cut a channel through to the Crookhaven River. Tidal flows and successive floods have deepened and widened the channel, which is known as Berrys Canal, and it has consequently become the main river channel. Shoalhaven Heads is now predominantly closed by a coastal sand barrier that is breached only during large flood events. (Umwelt 2005).

The total catchment area of the Shoalhaven River is approximately 7,300 km^2 (HRC 1999). Major tributaries in the upper reaches of the river include the Mongarlowe, Corang and Endrick Rivers. In the middle reaches, Bungonia Creek and Kangaroo River flow into the Shoalhaven River upstream of Tallowa Dam. Yalwal Creek with its tributaries of Ettrema, Bundundah, Danjera and Yarramunmun Creeks enters the river downstream of the dam. Further downstream, between the dam and Nowra, major tributaries include Nowra Creek, Cabbage Tree Creek, Mundamia Creek, Bangalee Creek and Calymea Creek. Bomaderry Creek and Broughton Creek are the main tributaries flowing into the lower Shoalhaven River estuary downstream of Nowra. (Umwelt 2005).

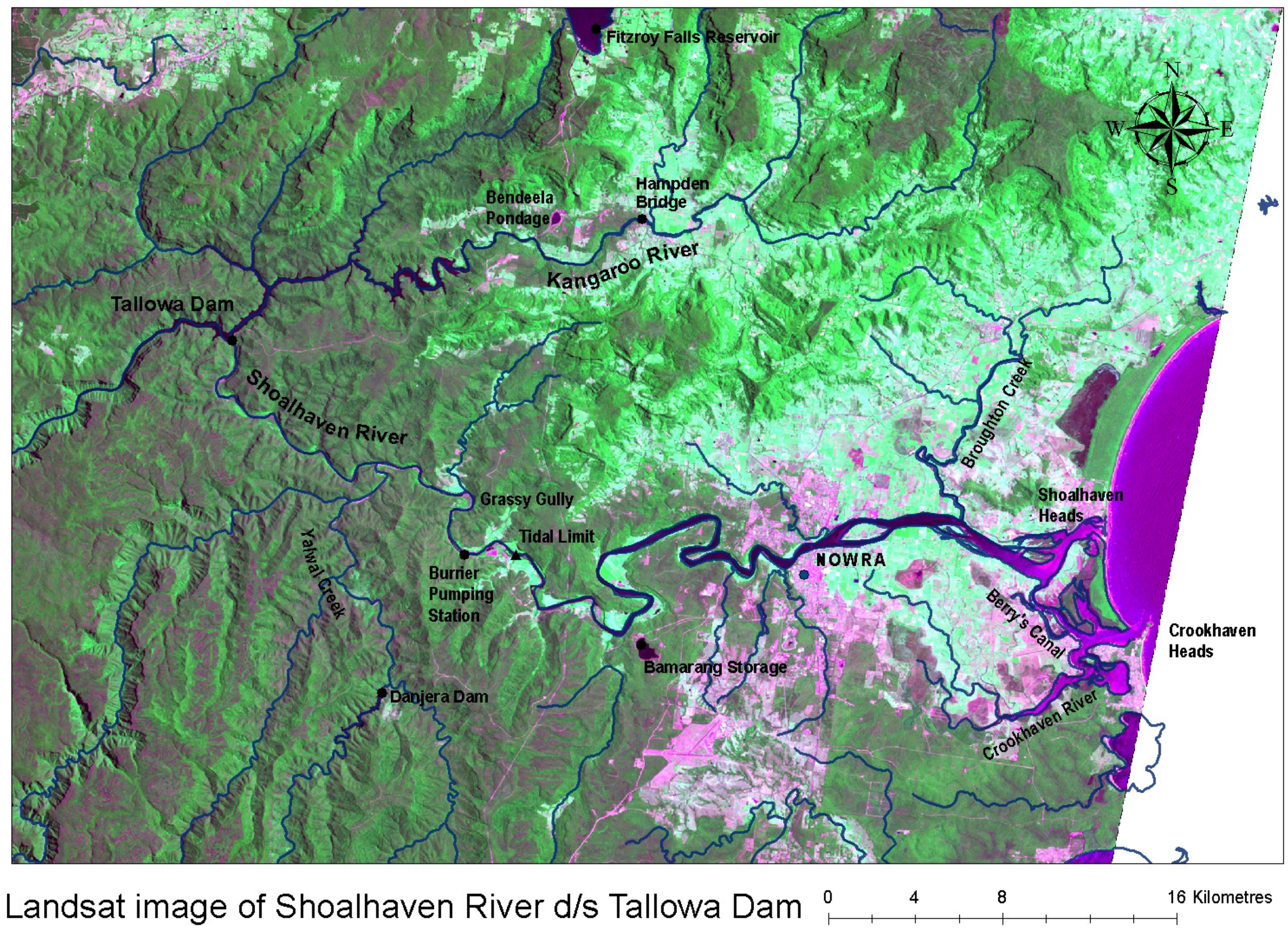
Key features of the Shoalhaven River downstream of Tallowa Dam are shown in Figure 2 on the next page.

2.2 Dam management and current environmental flow releases

Completed in 1976, Tallowa Dam is located at the confluence of the Kangaroo and Shoalhaven Rivers and has a capacity of 85,500 ML (SCA 2002). Lake Yarrunga is the storage formed by Tallowa Dam, and has a mean depth of 28 metres, a maximum depth of 35 metres and an area of approximately 9.3 km^2 (Norman and Turner 1999). Tallowa Dam, Lake Yarrunga and landholdings around the lake are managed by the SCA. Most of the inflows to Lake Yarrunga are passed by Tallowa Dam because the lake is a small storage relative to other storages in the region, but has a large catchment area with a relatively high runoff (HNRMF 2004).

The water offtake for transfers to the Hawkesbury-Nepean River System is located at Bendeela in the Kangaroo Valley arm of Lake Yarrunga. Bendeela Pumping and Power Station lifts water to Bendeela Pondage, a 1,200 ML reservoir at the foot of the escarpment. From there, Kangaroo

Figure 2. The Shoalhaven River downstream of Tallowa Dam. (Source: I. Reinfelds, DNR).



Valley Pumping and Power Station then further lifts the water to Fitzroy Falls Reservoir via a tunnel, shaft, pipeline and canal. From Fitzroy Falls Reservoir, water required to supplement the SCA storages in the Hawkesbury-Nepean River System is transferred via a canal, pumping station, tunnel and a second canal to Wingecarribee Reservoir. From Wingecarribee Reservoir water can be released into the Wingecarribee River, which flows into the Wollondilly River and Lake Burragorang, feeding the main Sydney supply system via Warragamba Dam. Water can also be released from Wingecarribee Reservoir via canals and pipelines collectively known as Glenquarry Cut into the Nepean River, which flows into Nepean Dam. From there it can be transferred to Sydney via the Upper Canal or to the Illawarra region via the Nepean-Avon tunnel to Avon Dam. (SCA 2002).

Since 1980, transfers from Tallowa Dam to the Hawkesbury-Nepean River System have occurred during three periods of drought, while in most years there have been no transfers. Approximately 430 GL (gigalitres) was transferred in 1980-84, 140 GL in 1994-95, and 260 GL in 2003-05 (as at July 2005).

Water is pumped up the system between Lake Yarrunga and Fitzroy Falls Reservoir using off-peak electricity. Some of the water is then released back down the system for the generation of electricity during periods of peak demand. The hydroelectric power generation is managed by Eraring Energy, and the power is fed into the state transmission grid through the Canberra-Dapto transmission line. (SCA 2002).

Tallowa Dam also has a spillway and controllable flow outlets to the Shoalhaven River. The flow outlets on the dam wall are two 1.2 metre x 1.2 metre pipes located at a fixed depth of approximately 20 metres below the spillway crest. Shoalhaven City Council extracts water downstream at Burrier, located between Tallowa Dam and Nowra. A weir at Burrier forms a large pool from which water is pumped to Bamarang Dam, located west of Nowra, and from there it is supplied to Council's water treatment plants. During periods of very low river flow, Council can boost the available supply at Burrier through releasing water from Danjera Dam, which is located on a tributary of Yalwal Creek. Yalwal Creek stretches for about 16 km before joining the Shoalhaven River between Tallowa Dam and Burrier. The weir at Burrier is not an engineered concrete structure, instead being made from riverbed material and rocks and boulders that are bulldozed into position. It is reformed occasionally to preserve the large pool for the pumping station.

Shoalhaven City Council also draws and treats water from Bendeela Pondage to supply treated water to Kangaroo Valley township (SCA 2002).

The current environmental flow for the Shoalhaven River downstream of Tallowa Dam is based on releases of up to 90 ML/day. Under current operating rules Tallowa Dam passes all inflows when the inflows are less than 180 ML/day. The flow between 90 and 180 ML/day is available for extraction by Shoalhaven City Council, which leaves 90 ML/day as the amount of water allocated to the environment below Burrier. The current operating procedures for the dam are:

1. When natural inflows to Lake Yarrunga are less than 90 ML/day, the SCA releases 100% of the natural inflow as the environmental flow and this release passes Burrier.
2. When inflow to Lake Yarrunga is between 90 and 180 ML/day, the SCA releases the environmental flow of 90 ML/day plus Shoalhaven City Council's requirements of up to a further 90 ML/day.
3. If inflows exceed 90 ML/day plus the Shoalhaven City Council requirement, the surplus is stored if there is dam capacity. If Lake Yarrunga is full, spill releases increase accordingly.

During low flow conditions when the flow is equivalent to or less than the environmental flow, Shoalhaven City Council will reduce or stop pumping at Burrier and obtain water from Bamarang Dam. If the low flow situation persists then Shoalhaven City Council will release water from Danjera Dam into Yalwal Creek to meet supply demand. If the low flow situation persists beyond the capacity of Danjera Dam, then water will be purchased from the SCA and released from Tallowa Dam.

2.3 Conceptual models

The Hawkesbury-Nepean River Management Forum Independent Expert Panel has defined three distinct river reaches below Tallowa Dam on the basis of hydrology, geomorphology and land use patterns (Table 1) (IEP 2004). ‘Hydrology’ is the study of the properties, distribution, and circulation of water on the surface of the land, underground, and in the atmosphere. ‘Geomorphology’ is the study of landforms and the processes that form them.

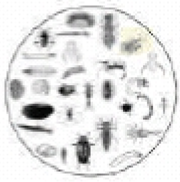
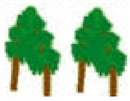
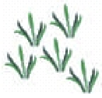
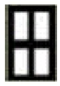
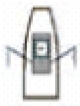
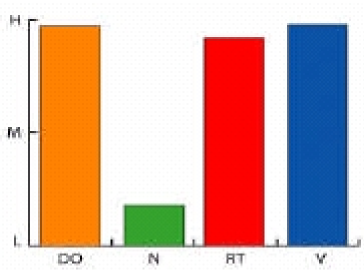
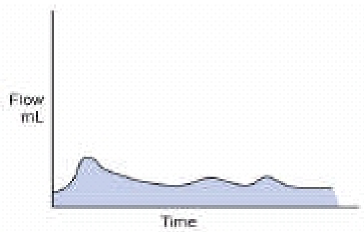
Table 1: Reaches defined by Hawkesbury-Nepean River Management Forum Independent Expert Panel. (Source: IEP 2004).

Reach Number	Location
R1	Shoalhaven River, Tallowa Dam to Burrier
R2.1	Shoalhaven River, Burrier to Nowra (Princes Highway Bridges)
R2.2	Shoalhaven River, Nowra to Pacific Ocean

The Independent Expert Panel has used the three river reaches as the basis for the development of ‘conceptual models’ (IEP 2004). The conceptual models are three-dimensional diagrams which illustrate the key characteristics of the three river reaches downstream of Tallowa Dam and introduce the potential impacts of the dam. A detailed review of knowledge of the river downstream of Tallowa Dam and the impacts of the dam is presented in the next Chapter (Chapter 3).

Figure 3 is a key to the symbols and graphs used in the conceptual models, which are shown in Figures 4, 5 and 6. The discussion accompanying each conceptual model draws primarily on the analysis of the Independent Expert Panel (IEP 2004), with some supplementary information also drawn from other reference sources.

Figure 3: Key to conceptual models. (Source: Adapted from IEP 2004).

Symbols used in Figures 4, 5 and 6			
Diversity of biotic communities		**Native aquatic macrophytes**	
		Exotic aquatic macrophytes	
Native riparian vegetation		**Exotic riparian vegetation**	
Wetland		**Native forest / woodland**	
Wetland emergent vegetation		**Sewage treatment plant**	
Recreational activities (water based)		**Recreational activities (land based)**	
Dam on tributary		**Commercial fishing**	
Aboriginal cultural heritage		**European cultural heritage**	
Graphs used in Figure 6			
Water quality parameters		**The bars indicate the Independent Expert Panel assessments for dissolved oxygen (DO), nutrient concentration (N), retention time in the reach (RT) and flow velocity (V) on a scale from low (L) through medium (M) to high (H), for both the natural and current situations.**	
Hydrographs		**The hydrographs show the Independent Expert Panel assessments for variability and magnitude of river flow as a function of time, for both the natural and current situations.**	

2.3.1 Conceptual models: Reach 1, Tallowa Dam to Burrier

Natural situation (upper diagram in Figure 4)

The freshwater reach immediately below Tallowa Dam consists of a sinuous river valley which is narrower in the upper half than the lower half. The reach is typified by a mixed sand and gravel bedload from upstream sources, with a well developed sequence of pools and riffles providing instream habitat variability (a 'riffle' is a shallow area of a river or stream where water flows rapidly over a gravel or rocky stream bed, as shown in the front cover photograph of this report). The natural situation for this reach would have been visually similar to the current situation. Fish passage would not have been impeded by the dam, and higher flows would have scoured riffles for habitat renewal. Energy sources and organic matter for the aquatic ecosystem in this reach would have been derived primarily from leaves and other forest litter fall from both adjacent riparian (riverbank) vegetation and drift from upstream areas.

Current situation (lower diagram in Figure 4)

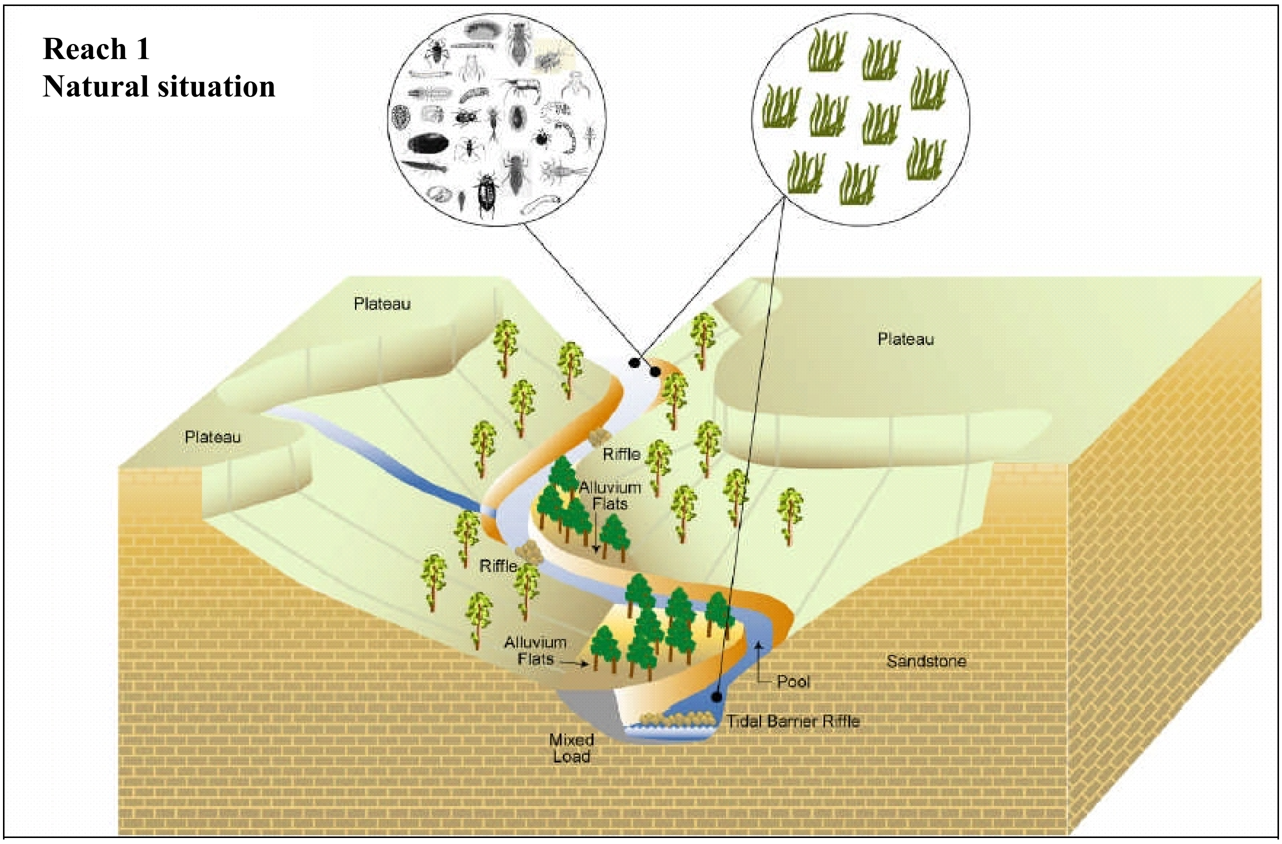
On the valley sides there has been limited land clearance for isolated farming, with little impact on flows or the river channel. Otherwise the landscape remains significantly unchanged from natural, with much of the valley in this reach protected in Morton National Park.

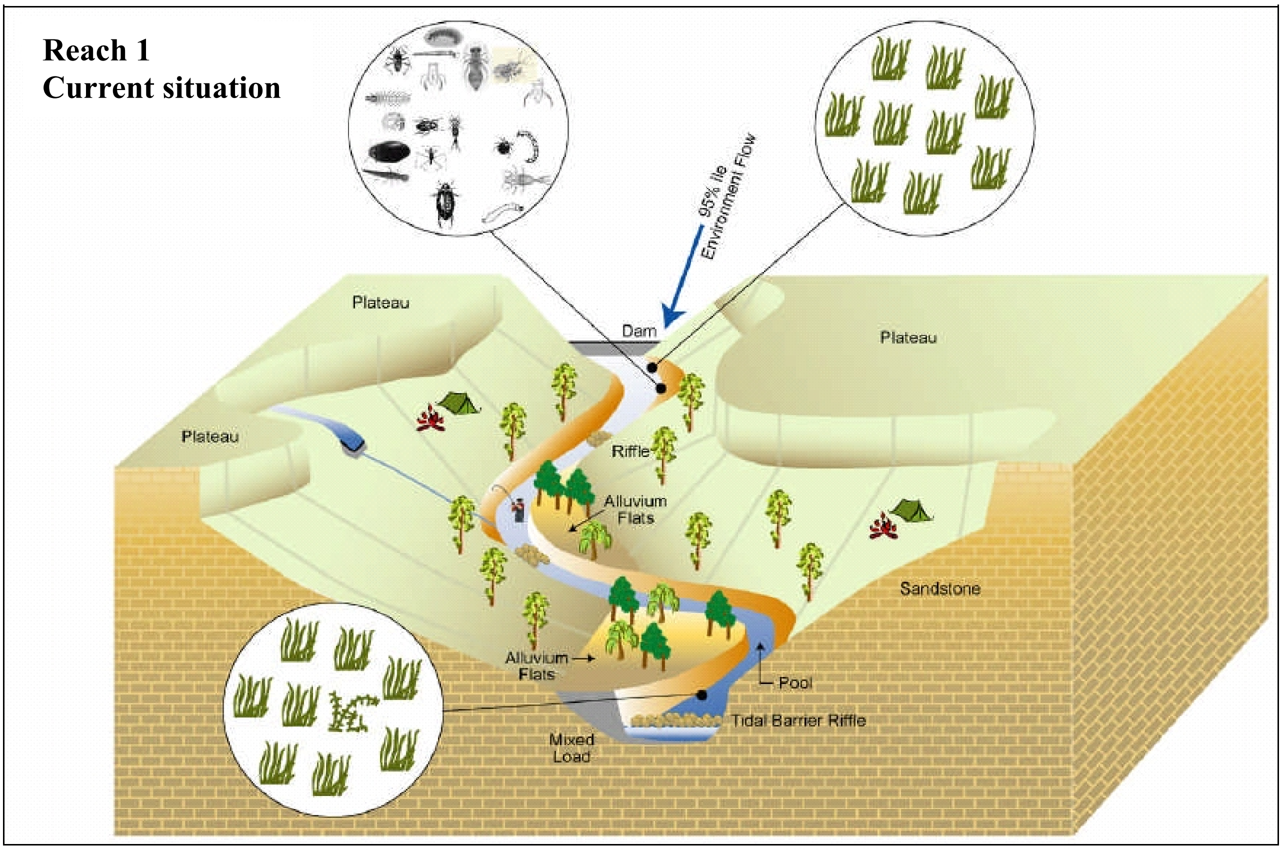
When natural inflows to Lake Yarrunga are less than 90 ML/day, the SCA releases 100% of the natural inflow as the environmental flow. This provisional environmental flow release has been suggested by the Hawkesbury-Nepean River Management Forum Independent Expert Panel to be providing an insufficient volume and depth of water over riffle habitats. Low water depth across these habitats is likely to limit connectivity between pools along the river, particularly for large-bodied aquatic animals such as fish. (Coysh *et al.* 2005).

Transfers from Tallowa Dam to the Hawkesbury-Nepean River System have been infrequent. However, the transfers have occurred during periods of drought when natural flows in the Shoalhaven River are low and typically well below average, meaning that the transfers would actually have represented a much larger proportion of flows during these periods (Coysh *et al.* 2005). The Hawkesbury-Nepean River Management Forum Independent Expert Panel alerts that the potential consequences of reduced flows in this reach include reduced biological diversity and the increased abundance of exotic aquatic flora at the expense of native species (as illustrated in Figure 4).

Because water released from the dam for the current environmental flow comes from pipes located in the dam wall at a fixed depth of approximately 20 metres below the spillway crest, discharges of cold and anoxic (having an absence of dissolved oxygen), nutrient and metal enriched water have been released when the water column is stratified, and this has posed a risk to fauna and flora. As a pilot measure to address this problem, the SCA recently installed a compressor and aeration system in Lake Yarrunga to mix warmer surface water with the cooler deeper water. A multilevel offtake, which would allow water to be released from different levels in the lake, is also being considered. (SCA 2005).

Figure 4: Reach 1, Tallowa Dam to Burrier. Source: IEP (2004).





2.3.2 Conceptual models: Reach 2.1, Burrier to Nowra

Natural situation (upper diagram in Figure 5)

All of this incised meandering reach is a tidal river, and is also described as the upper Shoalhaven River estuary (Umwelt 2005). Freshwater inflows pass over the tidal barrier riffle at Burrier to enter the reach. The river valley is wider than the upstream reach and slightly more sinuous. Lower parts of the reach have benches incised into the sandstone and alluvial deposition on these marks the site of former and present floodplains which would have been forested under natural conditions. The benches give a gorge-within-a-gorge effect, which protects the alluvial deposits from bank erosion and lateral migration of the river channel. As with the upstream reach, there is a mixed sand and gravel bedload, but sand becomes more dominant in the channel bed due to tidal influences. The wider river channel has had little shading, so the aquatic ecosystem would have been likely to gain more energy from algal/macrophyte photosynthesis than from land-based organic inputs. The macroinvertebrates would have been dominated by crustacea in this section, and there would have been few insects.

Current situation (lower diagram in Figure 5)

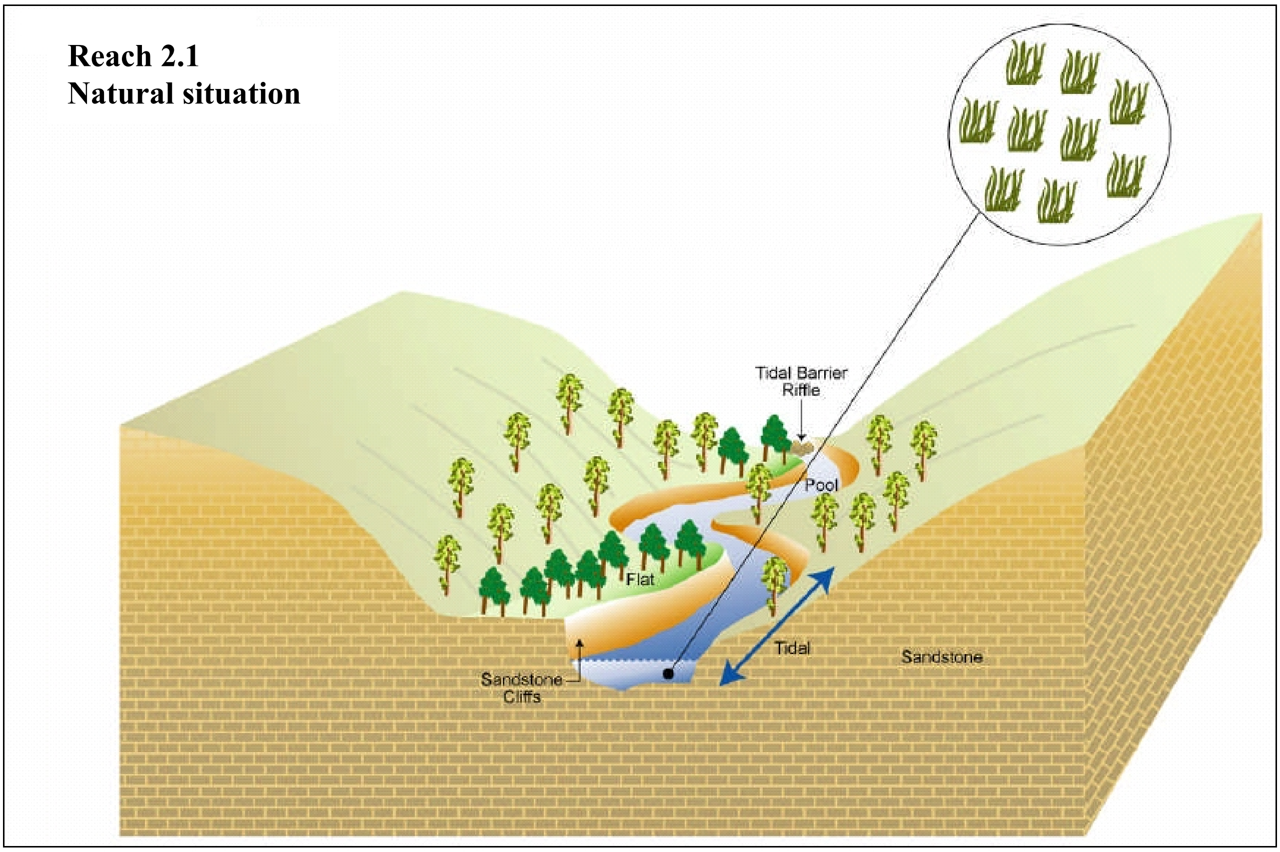
This reach has been more extensively cleared and has more catchment development and roads than the upstream reach. The Hawkesbury-Nepean River Management Forum Independent Expert Panel alerts that vegetation clearance is likely to have contributed to enhanced bank erosion (as illustrated in Figure 5).

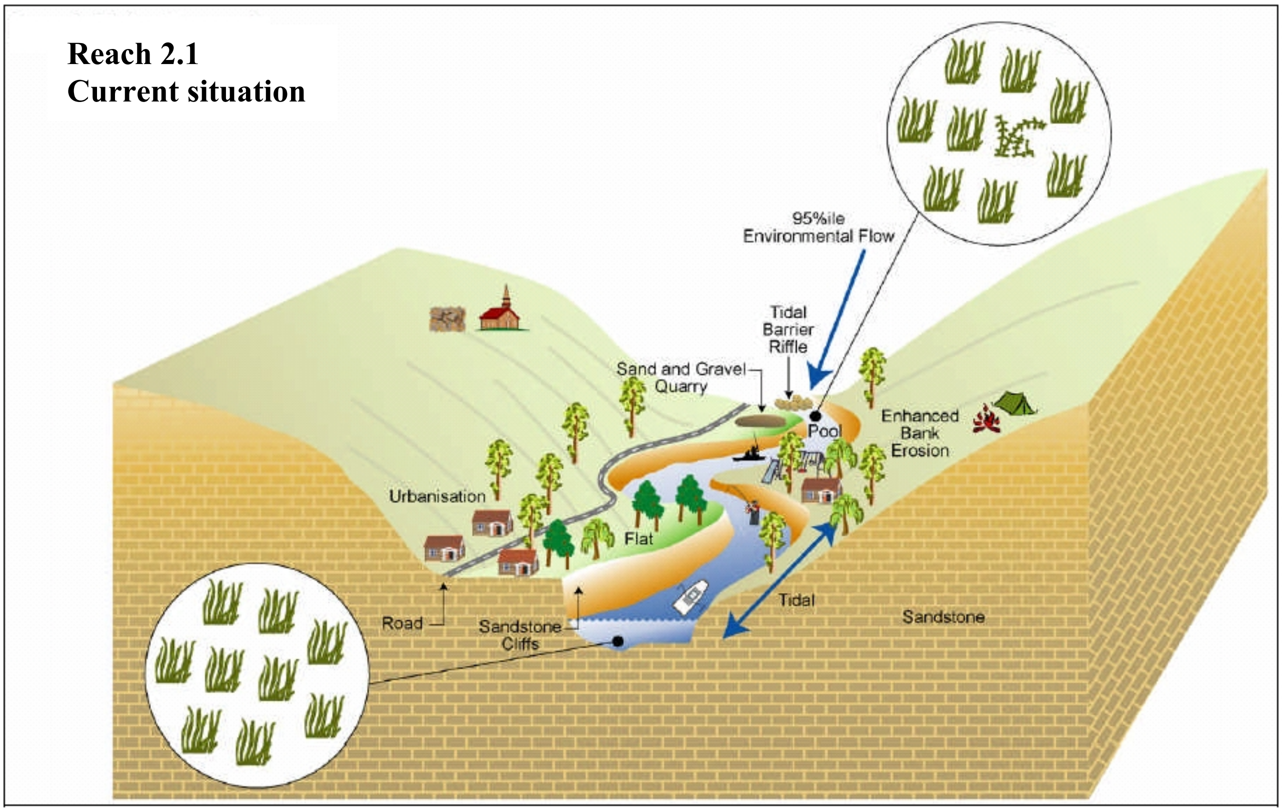
There is a risk that some current activities in this reach, for example sand and gravel extraction, could cause turbidity in the river which could spread for several kilometres ('turbidity' is the cloudy appearance of water caused by the presence of suspended particles). Increased turbidity may negatively affect the photosynthesis of algal/macrophyte populations, reducing the energy input into the aquatic ecosystem and affecting other components of the food web. The naturally small influence of any land-based energy and organic inputs will have been further reduced by the presence of Tallowa Dam, which would block drift from upstream waters.

Flows entering this reach are reduced by Shoalhaven City Council's extraction at Burrier, which occurs on a regular basis, and the transfers from Tallowa Dam to the Hawkesbury-Nepean River System. Transfers from Tallowa Dam to the Hawkesbury-Nepean River System have been infrequent. However, the transfers have occurred during periods of drought when natural flows in the Shoalhaven River are low and typically well below average, meaning that the transfers would actually have represented a much larger proportion of flows during these periods (Coysh *et al.* 2005).

The Hawkesbury-Nepean River Management Forum Independent Expert Panel alerts that the potential consequences of reduced flows in this reach include reduced connectivity between the tidal and upstream sections of the river due to reduced flows over the tidal barrier riffle, which would decrease the chances of fish movement and also affect the microhabitats within the tidal barrier riffle and the aquatic biota dependent on those microhabitats (as illustrated in Figure 5). Reduced flows could also cause saline waters to encroach upstream for a greater distance, duration or frequency than under natural conditions, which would affect the distribution of aquatic animals and plants, alter riparian vegetation, and kill freshwater aquatic macrophytes (plants) which are important nursery habitats for many fish species.

Figure 5: Reach 2.1, Burrier to Nowra. Source: IEP (2004).





2.3.3 Conceptual models: Reach 2.2, Nowra to Pacific Ocean

Natural situation (upper diagram in Figure 6)

This reach extends from the Princes Highway bridges at Nowra to the ocean, and is also described as the lower Shoalhaven River estuary (Umwelt 2005). The reach is dominated by tidal processes (Lawson and Treloar 1996), with occasional freshwater flushes occurring when the river is in flood. These freshwater flushes are important for estuarine health (Coysh *et al.* 2005). River floods would also have inundated parts of the low flat coastal floodplain, which has formed since the sea level returned to its present level some 6,000 years ago. Distributary channels, wetlands and lagoons are features of the floodplain, which would have been densely forested away from these features. In-channel sedimentation is apparent from the numerous estuary islands, shoals and sand flats.

Current situation (lower diagram in Figure 6)

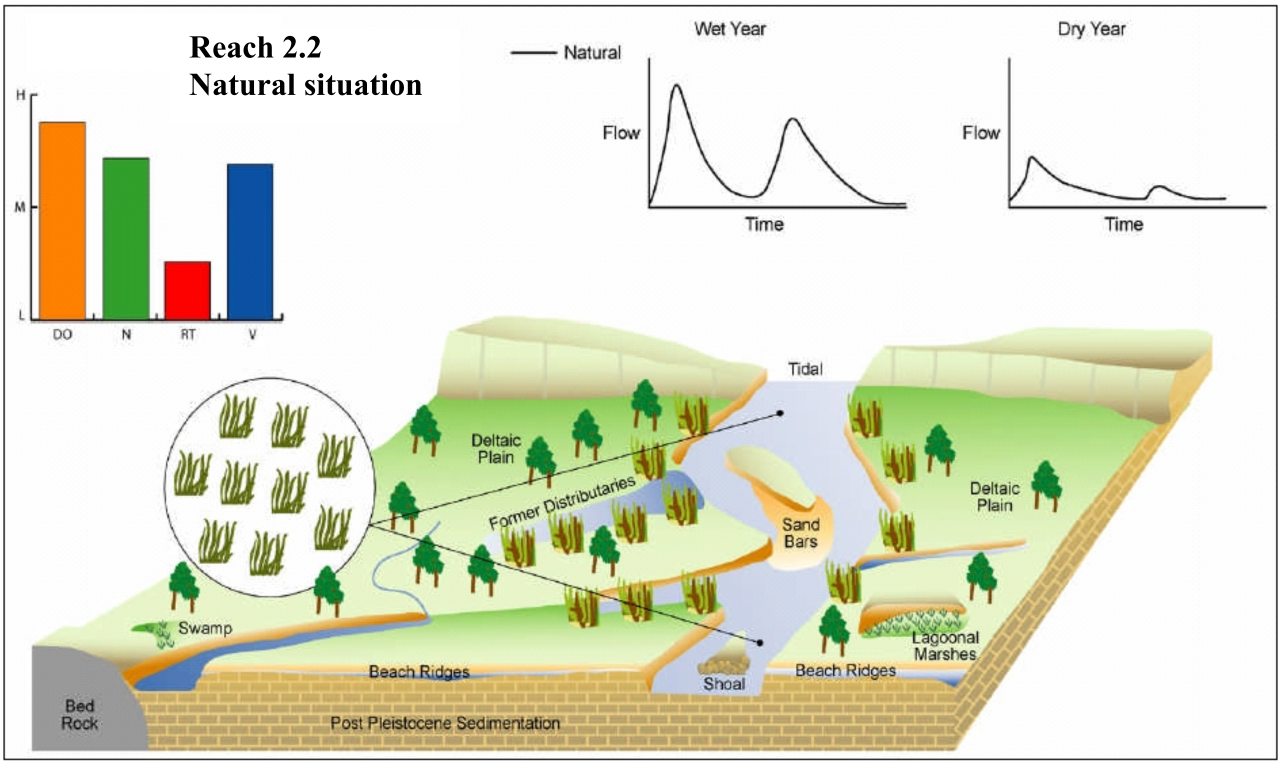
The floodplain has been cleared, drained in many places and settled for farming. Urban areas are found on the higher margins of the floodplain and at the river heads. Flood mitigation measures undertaken mainly in the 1960's mean that only the largest floods can now connect with the floodplain wetlands temporarily. As well as levee repair, the flood mitigation measures involved the installation of floodgates on tributaries to contain floodwaters to the river until the levees are topped. After flooding, the floodwaters are then drained through the floodgates which are opened at low tide.

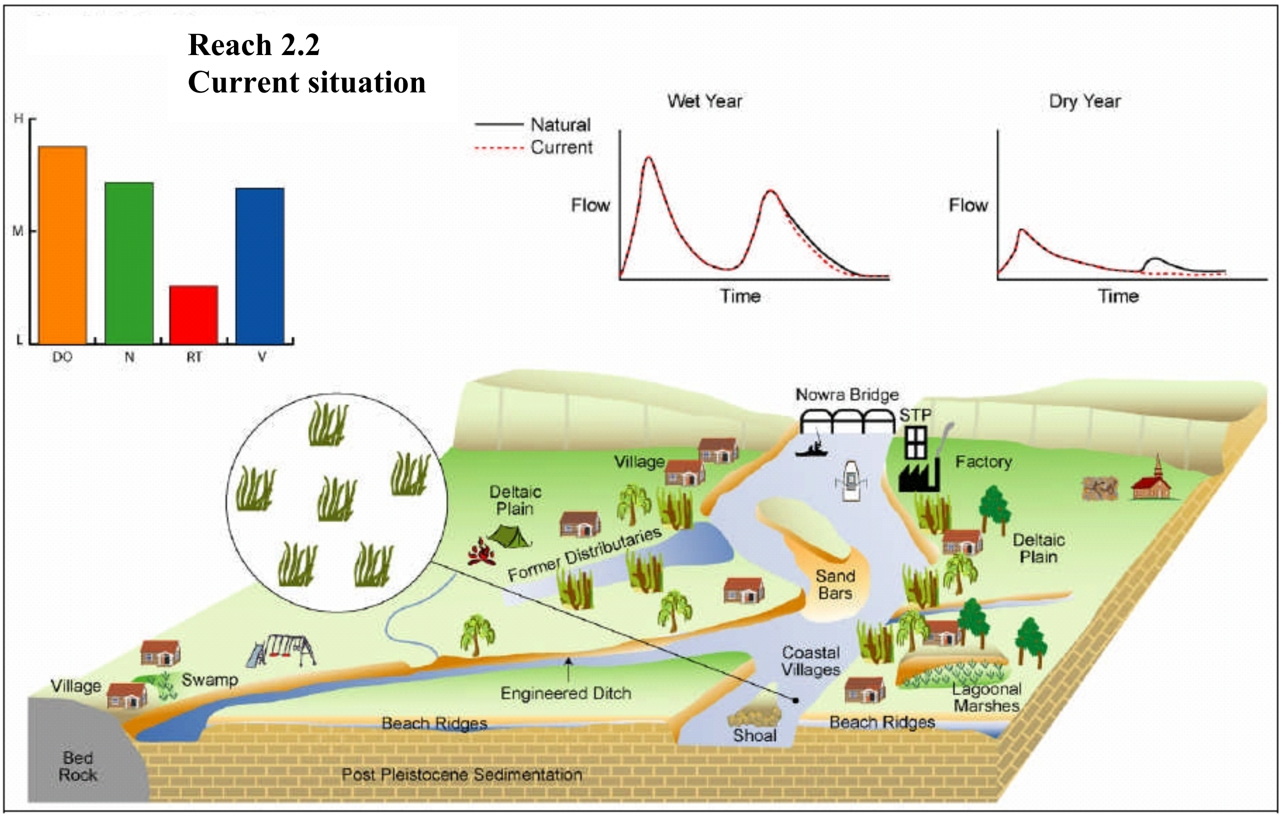
The current opening to the ocean is at Crookhaven Heads. Historically, the entrance was further north at Shoalhaven Heads; however in 1822 the European settler Alexander Berry cut a channel through to the Crookhaven River. Tidal flows and successive floods have deepened and widened the channel, which is known as Berrys Canal, and it has consequently become the main river channel.

The Hawkesbury-Nepean River Management Forum Independent Expert Panel concluded that prior to the construction of Berrys Canal the Shoalhaven River channel would only have been tidal after freshes and floods which opened the entrance at Shoalhaven Heads, while in lower flow periods long-shore sand drift would have blocked the entrance from tidal flow. This would mean that the construction of Berrys Canal would have introduced permanent tidal conditions to the estuary, significantly altering estuarine ecology (as illustrated in Figure 6). However, the conclusion that the Shoalhaven Heads entrance was closed in lower flow periods is not supported by studies carried out in the 1980's for and by the NSW Public Works Department (Nittim and Cox 1986, PWD 1988). These studies concluded that prior to the construction of Berrys Canal it is likely that the Shoalhaven Heads entrance would have been permanently open, and that the construction of Berrys Canal has reinforced the natural shoaling of the Shoalhaven Heads entrance and scouring of the Crookhaven Heads entrance, resulting in a continuing process of capture of the Shoalhaven Heads entrance by the Crookhaven Heads entrance. Due to the progressive diminution of flows, the Shoalhaven Heads entrance is now predominantly closed by a coastal sand barrier that is breached only during large flood events (Umwelt 2005).

Because this reach is dominated by tidal processes, the reductions in inflow due to Shoalhaven City Council's extraction at Burrier and the transfers from Tallowa Dam to the Hawkesbury-Nepean River System are likely to have had a lesser impact than in Reaches 1 and 2.1 (Lawson and Treloar 1996).

Figure 6: Reach 2.2, Shoalhaven River, Nowra to Pacific Ocean. Source: IEP (2004).





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3. Knowledge review

This Chapter presents a detailed review of the current knowledge relating to environmental flows in the Shoalhaven River downstream of Tallowa Dam, drawing on the advice of the CRC for Freshwater Ecology and specialists in NSW Government agencies and DNR's examination of the results and recommendations of key studies (for further information on these studies refer to Section 1.4).

The CRC for Freshwater Ecology advises that the knowledge of environmental flows, flow-ecology relationships and the Shoalhaven River system has increased considerably in the six years since the publication of the 1999 Macquarie University Background Report *Issues relating to the determination of environmental flows for the Shoalhaven River* (Norman and Turner 1999), however some information gaps remain.

3.1 Fluvial geomorphology

3.1.1 Geomorphological setting

Fluvial geomorphology is the study of river processes and form. The 'River Styles' analysis procedure, developed at Macquarie University, examines river character and behaviour in a catchment framework. The Shoalhaven River below Tallowa Dam has been divided into two River Styles in the Report *River Styles in the Shoalhaven Catchment, South Coast, NSW* (Brierley *et al.* 1999), a 'confined valley with discontinuous floodplain' River Style and a 'tidal' River Style. The Report notes that one of the River Styles, the Tidal River Style, covers both the bedrock controlled river reach which extends approximately 20-25 km upstream of Nowra and the coastal plain river reach downstream of Nowra, meaning that there are three distinct reaches below Tallowa Dam. As discussed in Section 2.3, the Hawkesbury-Nepean River Management Forum Independent Expert Panel has also defined three distinct river reaches below Tallowa Dam on the basis of hydrology, geomorphology and land use patterns (IEP 2004).

3.1.2 Sediment transport

The lack of significant sediment cover over the steeply sloping continental landscape of southern NSW has resulted in a comparatively low rate of sediment supply to the lower Shoalhaven River (Norman and Turner 1999). Additionally, Tallowa Dam now acts as a sediment trap. However, the sediment loading of the Shoalhaven River appears to increase downstream of the Yalwal Creek confluence, as localised instream sedimentation has formed broad bends with point bars (Brierley *et al.* 1999). There is insufficient information available on sediment movement in the Shoalhaven River in regard to the effects of flow on channel processes and hence habitat for various organisms (Coysh *et al.* 2005).

3.1.3 Acid sulfate soils

Acid sulfate soils contain natural deposits of iron sulfide and are usually associated with low lying floodplains. The soils can indirectly have a marked negative impact on receiving waters because of drainage that is acidic and high in toxic elements. Acid sulfate soils are found on the Shoalhaven floodplain. When the soils are left undrained few problems arise, however since European settlement the soils of the Shoalhaven floodplain have been cleared and drained to make them suitable for agriculture. Oyster embryos are markedly affected by acid sulphate soil drainage

(Wilson and Hyne 1997), so concerns about potential acid sulphate soil drainage have been expressed by growers in the Shoalhaven catchment (White 2001).

This reach of the river is dominated by tidal processes, and flood mitigation works on the floodplain mean that only the largest freshwater river floods can now reach the acid sulfate soils. Because of this, changes to the hydrology of the Shoalhaven River as a result of Tallowa Dam and associated transfers are unlikely to be a driving factor for acid production on the floodplain (Coysh *et al.* 2005).

3.2 Hydrology

Hydrology is the study of the properties, distribution and circulation of water on the surface of the land, underground, and in the atmosphere.

3.2.1 Major extractions

As discussed in Section 2.2, Shoalhaven City Council extracts water from the Shoalhaven River at Burrier, and the SCA can transfer water from Tallowa Dam to the Hawkesbury-Nepean River System.

The Shoalhaven City Council State of the Environment Report 2003-2004 provides Council's extraction amounts compared to Tallowa Dam inflow for the 2000-2004 period (SCC 2004):
- 16,211 ML was extracted in 2000/01 (total Tallowa inflow unavailable);
- 16,502 ML was extracted in 2001/02 (3.55% of Tallowa inflow);
- 16,985 ML was extracted in 2002/03 (7.32% of Tallowa inflow); and
- 15,675 ML was extracted in 2003/04 (11.55% of Tallowa inflow).

Council advises that in the 2000-2004 period it complied with the guideline to not pump water from Burrier when inflow to Tallowa Dam was less than 90 ML/day (Coysh *et al.* 2005).

When the combined storage of the dams that supply water to the greater Sydney region falls below 60%, water can be transferred from Tallowa Dam and directed to either Warragamba Dam or Nepean Dam (Varley 2002). Since 1980, transfers from Tallowa Dam have occurred during three periods of drought:
- approximately 430,000 ML (430 GL) was transferred in 1980-84;
- approximately 140,000 ML (140 GL) was transferred in 1994-95; and
- approximately 260,000 ML (260 GL) was transferred in 2003-05 (as at July 2005).

3.2.2 Other water users

There are also a number of other licensed water users downstream of Tallowa Dam. The amount of water used is small compared to Shoalhaven City Council's extractions and the SCA's transfers.

In addition, the *Water Management Act 2000* permits landowners with a direct river frontage to extract water for domestic purposes and stock watering under one of three types of Basic Landholder Rights. There is no record of the amount of water these users extract, but it should be determined as these extractions affect the actual amount of water received by the environment (Coysh *et al.* 2005).

3.2.3 Discharges

As well as the range of extractions, there are discharges of wastewater into the Shoalhaven River estuary from several sources. The amount of water discharged is small compared to the overall amount of water extracted.

3.2.4 Flow monitoring and modelling

Monitoring sites upstream of Tallowa Dam provide an indication of flows into the dam, and information at the dam is provided by gauges recording level and discharge. The main monitoring site of interest downstream of the dam is Grassy Gully, as records have been kept since 1964. (Norman and Turner 1999).

In 2002, the Snowy Mountains Engineering Corporation (SMEC) examined river flows in the Hawkesbury-Nepean, Shoalhaven and Woronora river systems (SMEC 2002a, SMEC 2002b, SMEC 2002c). The objective of this study was the compilation of data for both natural and existing river flow conditions to assist the Hawkesbury-Nepean River Management Forum Independent Expert Panel (IEP) determine appropriate environmental flows.

Ideally, such a study would be undertaken by comparing actual stream flow gauging records. However, stream flow records for the period prior to dam construction are limited, and flow conditions have been constantly changing over time due to dam construction and extraction for water supply, irrigation and other human uses. Because of this, flows that would have been experienced prior to the construction of the dam need to be simulated through the use of models. Models may utilise recorded stream flows or they may apply recorded rainfall to a catchment process module to compute runoff. They are capable of simulating the storage behaviour of dams, flow along river reaches and extractions for irrigation and town water supply.

Flows outputs from SCA modelling were used in the SMEC (2002a) study to provide a comparison of actual and natural flows from Tallowa Dam. The SMEC comparisons included assessments of both ‘average’ flows and ‘median’ flows. The ‘average’ (also called the ‘mean’) is defined as the sum of all of a set of flow values divided by the number of values in the set. The ‘median’ (also called the ‘50th percentile’) of a set of flow values is the middle value when all values are ranked in order, so that there are an equal number of values that are both larger and smaller than that value. An examination using ‘median’ flows can often be more informative because large short-term flood events in a relatively dry period can severely distort ‘average’ flow assessments.

When average flows were considered, transfers from Tallowa Dam to the Hawkesbury-Nepean River System were found to represent 15 GL per year or approximately 2.5% of the average water supply consumption of 600 GL per year. However because the transfers primarily occur during drought periods they actually represent a much larger proportion of annual consumption during those periods. (SMEC 2002c).

When median flows were considered, the river downstream of Tallowa Dam was found to receive 91% of natural flow. However, when low flows were examined, it was estimated that the ratio of actual to natural flow was only 5% which is a marked reduction on the median condition. This is because the transfers from Tallowa Dam occur during low flow periods. Hence, while the mean and median flows of the Shoalhaven River are reduced by only negligible amounts, the impact during low flow periods is severe. (SMEC 2002c).

It should be noted that most of the modelling for the SMEC study was based on monthly flow data. However, the Shoalhaven River experiences extreme variability in flow, with flows often changing from one day to the next (The Ecology Lab 1996). This means that models based on daily or even hourly flow data are required to facilitate an accurate determination of the amount of water required to provide suitable species habitat and a better understanding of the aspects of the flow that are important for the health and reproduction of various species (Coysh *et al.* 2005).

3.2.5 Groundwater

In general, the Shoalhaven River catchment is not noted for its groundwater resources (Coysh *et al.* 2005). However, the Southern Highlands is noted for its high yielding and high quality water (Pritchard *et al.* 2004) and there is some concern that extraction of groundwater from the headwaters of the Kangaroo River may impact on base flows in the river system. Additionally, Boro Creek has a higher base flow than relatively similar catchments in the upper catchment, and is likely to be predominantly groundwater driven (Green 2005).

The Shoalhaven River floodplain has relatively high water tables, with ground water being brackish to saline (SCC 2000). Groundwater flows in the floodplain are unknown.

More information on groundwater is desirable as the interaction of groundwater with the river can affect river hydrology and ecology (Coysh *et al.* 2005).

3.3 Water quality

3.3.1 Water quality monitoring

The SCA monitors the water quality of Lake Yarrunga and the Shoalhaven River upstream of the lake, and the SCA and Shoalhaven City Council monitor water quality in the Shoalhaven River below Tallowa Dam. Water quality results for the SCA area in 2002-2004 (SCA 2003, SCA 2004) and for the Shoalhaven City Council area between 2000-2004 (SCC 2004) are presented in the following subsections.

Council monitored all water catchments over the reporting period for the presence of algal blooms as well as regularly testing all water supply ponds. During the reporting period (2000-2004) levels of potentially toxic blue-green algae species were below incident levels (SCC 2004). Since 2001, blue-green algae monitoring in Kangaroo Valley has been undertaken by the SCA, with the sampling closely linked to the water transfers between Fitzroy Falls Reservoir, Bendeela Pondage and Lake Yarrunga (Coysh *et al.* 2005).

Current water quality monitoring is inadequate in terms of the study design and the variables that are measured (Coysh *et al.* 2005). There is a lack of analysis of water quality data in terms of its relationship to ecology, and more focussed monitoring is needed of variables and indicators relevant to ecological outcomes. The number of sites and their location also needs to be based on a statistically robust design that will inform the level of confidence that can be placed on results.

3.3.2 Lake Yarrunga

The SCA's 2002-2003 report on water quality found that Lake Yarrunga was the poorest of all the SCA reservoirs, with guideline values for key indicators regularly exceeded at most monitoring sites (Coysh *et al.* 2005). Monitoring also detected minor non-compliances for total nitrogen, total aluminium and faecal contamination at most sites between 2002 and 2004 (SCA 2003, SCA 2004).

Generally, the cyanobacteria (blue-green algae) data indicated low levels of total cyanobacteria and toxic cyanobacteria at all sites in the system, except at the Kangaroo Arm (Reed Island) site on Lake Yarrunga where the cyanobacteria total count exceeded the guideline in 45% of samples in 2002-03 (SCA 2003). Predictions have previously been made that high nutrient levels in the Kangaroo River could lead to algal problems (Norman and Turner 1999).

Water pH exceeded guidelines regularly at most locations in Lake Yarrunga in 2003-2004. However, all values were within 0.9 pH units of the guideline for reservoirs (pH 7.2). The neutral to mildly alkaline samples obtained is consistent with the samples taken in 2002-2003 (SCA 2004). Dissolved Oxygen (DO) saturation, total iron, chlorophyll-*a* and total phosphorus exceeded the guideline values regularly at most sites in 2003-2004, again following the trend of 2002-2003. Low levels of cyanobacteria and toxigenic cyanobacteria were detected at all sites in 2003-2004, except for two sites where the guidelines for cyanobacteria total count were exceeded 22 percent and 11 percent of the time, respectively (SCA 2004).

In 2003-2004, samples measured for Schedule 4 substances (pesticides, heavy metals, chemical and radiological substances) complied on all occasions (SCA 2004).

A study was undertaken in late 2003 to determine the effect on water quality of Lake Yarrunga of a drawdown of the water level by nearly four metres, exposing more than 80 hectares of lake bottom in the Kangaroo arm of Lake Yarrunga. The objective of the study was to determine whether bottom sediments directly exposed to sunlight would release nutrients in a bio-available form when the lake re-flooded, as indicated by nitrogen and phosphorus levels and algal blooms. The analysis found no significant nutrient release from the re-flooded sediments or increase in algal abundance (SCA 2004).

3.3.3 Shoalhaven River

Shoalhaven City Council tests the Shoalhaven River on a quarterly basis for physical and chemical variables (dissolved oxygen, pH, conductivity, salinity and temperature), as well as for faecal contamination. Additionally, selected sites in each catchment are tested for nitrogen, phosphorus and chlorophyll-*a*. It is not stated whether total or available nutrients are measured. Council has adopted a water quality index that weights each water quality variable to provide an overall water quality assessment for a site. They note that this has been done for simplicity and that it is not a precise representation. It is also not clear what ecological features the overall index actually represents, or how it helps manage water quality for environmental outcomes. For example, elevated concentrations of phosphorus may have little effect on biota (except perhaps plants) while ammonia and low dissolved oxygen may be lethal. Therefore, if dissolved oxygen was at critically low concentrations, water quality should fail regardless of the values of all other measures, but elevated concentrations of phosphorus would not be considered similarly. (Coysh *et al.* 2005).

The impact of flows and particularly flushing flows on water quality should be further investigated, and also the relationship between flow and the transport of organic matter and nutrients down the river and into the estuary (Coysh *et al.* 2005).

Tallowa Dam to Burrier

The current layout and numbers of monitoring sites between Tallowa Dam and the ocean is insufficient to fully determine the effects of the dam or dam operations on water quality in the Shoalhaven River (Coysh *et al.* 2005), however several dam impacts are clearly evident. Shoalhaven City Council monitors water quality at only one site between Tallowa Dam and Burrier, located directly below the dam, with the next monitoring site 20 km further downstream at Grassy Gully.

Water temperature is monitored by the SCA for their Water Management Licence requirements. Temperature measurements changed little between the 2002-2003 and 2003-2004 periods, with both periods showing the same longitudinal trend above and below the dam (Coysh *et al.* 2005). An analysis of the SCA data for 2003-2004 shows that Tallowa Dam has had the effect of suppressing water temperature in summer and spring and elevating water temperature in winter (pers. comm. Allan Lugg, NSW Department of Primary Industries). The temperature suppression in summer and spring has resulted from the release of water from outlets in the dam wall 20 metres below the spillway crest when the dam is stratified. In a stratified water body, distinct layers of different temperature, density and water quality develop at various depths with a restriction of mixing throughout the water column, so that a less-dense surface layer generally overlays bottom waters that are cold, dense, low in oxygen and low in quality. Temperature is the major contributing factor, with stratification generally occurring as surface waters warm in summer and spring. Cold water pollution from dam releases has been linked to impacts on native plants and animals including the localised extinction of some species, and impacts on the recreational amenity of rivers. (IEP 2004).

The summer and spring temperature suppression effect has been observed immediately below Tallowa Dam, however further downstream at Grassy Gully the temperature recovers to approximately the same temperature as the Shoalhaven River above Lake Yarrunga (pers. comm. Allan Lugg, NSW Department of Primary Industries). There are no other monitoring sites between Tallowa Dam and Grassy Gully, which is 20 km downstream from the dam, meaning that it has not been possible to determine how far downstream from the dam the cold water pollution impacts have extended or if measures to address the problem will be effective (Coysh *et al.* 2005).

Stratification of the water column in Tallowa Dam can also lead to the release of iron, manganese and aluminium from bottom sediments into the water column which, if discharged from the dam can lead to similarly elevated concentrations of these elements in downstream receiving waters. When iron-rich bottom waters are exposed to the atmosphere the iron oxidises and quickly precipitates leaving a rusty-coloured precipitate. This process is mediated by iron-oxidising bacteria, which can also be seen as a rusty coloured mass in the water. Iron precipitate and iron-oxidising bacteria have been particularly evident in the Shoalhaven River immediately downstream of the dam. The implications of this are the direct loss of both native plants and animals or the loss or simplification of habitat. Monitoring data indicates that elevated concentrations of total and filterable iron have occurred immediately downstream of Tallowa Dam, and these concentrations have often been in excess of those recommended in the ANZECC/ARMCANZ (2000) guidelines. (Coysh *et al.* 2005).

Another potential problem is the risk of the downstream release of the high levels of cyanobacteria (blue-green algae) that have been recorded in the Kangaroo Arm of Lake Yarrunga (Coysh *et al.* 2005). However, this risk has already been addressed in SCA's Water Management Licence (DLWC 2001b).

Downstream of Burrier

Wastewater is discharged into the Shoalhaven River estuary from several sources (Coysh *et al.* 2005). Shoalhaven City Council describes the water quality as good at the five sites they monitor along the Shoalhaven River (SCC 2004). Occasionally the water quality index for these sites drops to a lower medium rating, which is attributed to periodic low dissolved oxygen and high phosphorus.

Stratification of natural pools

Stratification of the deep natural pools in river systems is a common phenomenon and can have significant impacts on both water quality and pool-dependent plants and animals. Deep pools occur in the Shoalhaven River downstream of Tallowa Dam, and while stratification of these pools can occur naturally, the frequency, duration and magnitude of stratification events could be exacerbated by prolonged low flows caused by transfers from Tallowa Dam to the Hawkesbury-Nepean River System. (IEP 2004).

High freshwater short term events in river systems, in particular flood flows, help to mitigate the effects of stratification by flushing out deep pools with fresh water (Coysh *et al.* 2005).

Salinity

The Hawkesbury-Nepean River Management Forum Independent Expert Panel examined Shoalhaven River estuary salinity during a field trip on 10-11 February 2003 (IEP 2003). Approximately 50 km (approximately 96% of the total length) of the Shoalhaven River estuary was traversed, and estuary salinity-depth profiles were recorded at approximately five kilometre intervals. The Independent Expert Panel concluded that the low salinity zone of the estuary had been greatly compressed, that much greater compression (i.e. higher salinity further upstream) had occurred approximately one month earlier, and that changes in the distribution of two aquatic plants between 1994 and 2003 was likely to be due to increased salinity in the estuary (Coysh *et al.* 2005). Water extractions were identified as a potential contributor to this compression of the low salinity zone (IEP 2003).

Different conclusions were drawn in hydrological investigations completed in 1996 for Shoalhaven City Council (Lawson and Treloar 1996). These investigations found that the Shoalhaven River estuary was dominated by tidal processes for the range of freshwater inflows investigated (14, 90, 146, 245, 355, and 394 ML/day). Changes in freshwater inflow only had a significant effect in a "zone of influence" from 0 to 6 km downstream of Burrier, and high freshwater short-term events were found to only have a short temporary effect on the salinity regime in the "zone of influence".

Further investigation is needed to resolve the uncertainty in regard to the salinity regime in the Shoalhaven River estuary and the impact of freshwater extractions on that regime. The Hawkesbury-Nepean River Management Forum Independent Expert Panel has recommended that detailed numerical modelling of the estuary be carried out in association with examining the inflow/salinity responses of ecological indicators (IEP 2003).

In addition to the possible compression of the low salinity zone of the estuary, freshwater extractions could be changing the variability of the salinity regime or reducing the volume or frequency of flushing flows (Coysh *et al.* 2005).

In an analysis of the data collected by Lawson and Treloar (1996), The Ecology Lab (1996) found that the salinity of the Shoalhaven River estuary is likely to be highly variable, particularly in the upper estuary. The standard deviation, a measure of absolute variability under low flow conditions, suggests maximum variability in salinity occurs about 25 km downstream of Burrier under the ebb tide and about 20 km downstream of Burrier for the flood tide. The Ecology Lab (1996) alerts that the impact of freshwater extractions on salinity variability may be ecologically significant for the Shoalhaven, as at least one study has shown that standard deviation of salinity, rather than mean salinity, could be a better predictor of the distribution and biomass of aquatic flora and fauna (Montague and Ley 1993).

3.4 Ecology

3.4.1 Fish

Gehrke *et al.* (2002) looked at the changes in fish communities in the Shoalhaven River 20 years after the construction of Tallowa Dam. The effects of the dam on the fish communities were studied by comparing species abundances, population size-structures and the structure of fish communities above and below the dam. The study showed that Tallowa Dam is a major barrier to fish migration, with 21 species downstream of the dam, compared to 16 species above the dam. Reconstructed historical fish distributions in the Shoalhaven River system suggest that before 1974 the fish community followed a continuum from the tidal limit to at least 130 m elevation, which is located upstream of Lake Yarrunga approximately 30 km from the Tallowa Dam wall. Ten diadromous species are believed to be extinct above the dam because of obstructed fish passage (migratory fish species can be grouped into a number of categories, one of these being 'diadromous', which are fish species that migrate between fresh and salt water during their life cycle). Congregations of juvenile fish directly below the dam were evident, and it is estimated that the dam blocks access by migratory fish to 75% of upstream tributaries in the Shoalhaven catchment, a significant loss of potential habitat from the system. Migratory fishes are estimated to represent 96% of the native freshwater fishes potentially occurring in the catchment (Gehrke *et al.* 2001).

The Shoalhaven River has special significance for fish conservation because it has provided permanent habitat for the Australian grayling (Gehrke *et al.* 2002). This species is listed as vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and protected in New South Wales and Victoria. Gehrke *et al.* (2002) report that recent surveys collected only a single specimen from the Shoalhaven system downstream of the dam. Australian bass was the only diadromous fish to be found upstream of the dam, but this is most likely because hatchery-reared Australian bass have been stocked into Lake Yarrunga. Carp, a non-native species, was the only species that was abundant both upstream and downstream of the dam and that showed no difference in size distributions of individuals upstream and downstream. The modal population size (which is the most common size) of flat-headed gudgeon and Australian smelt was significantly lower downstream of the dam. The size structures of Australian bass populations were also significantly different upstream and downstream of the dam, reflecting the growth of the hatchery-reared bass upstream (Gehrke *et al.* 2002).

In summary, the physical presence of the dam has led to the following changes to fish communities in the Shoalhaven River:

- altered species diversity upstream of the dam because of localised extinction of migratory fish and changes in abundance of remaining species;
- divergence of fish communities between lake habitats within impoundments and riverine habitats upstream of impoundments;
- creation of an artificial discontinuity between fish communities upstream and downstream of the dam;
- divergence of populations of species that live upstream and downstream of the dam;
- accumulations of fish directly below the dam wall;
- changes in the structure of the downstream fish community;
- establishment of non-native species; and
- reduced upstream biomass of predators near the top of the food web such as Australian bass.

Tallowa Dam to Burrier

Gehrke *et al.* (2001) tracked the movements of Australian bass and striped mullet in the Shoalhaven River using radio telemetry. Australian bass remained near the base of the dam wall and only moved small distances. Similarly, striped mullet did not make large-scale movements from their place of capture. Within the complex pool and rapid flow environment at the base of Tallowa Dam, Australian bass congregated within the flow discharged from the base of the dam in preference to flow from the spillway. Flow appeared to be the major factor attracting Australian bass to the base of the dam, despite the lower temperature of water released from the outlet valve (Gehrke *et al.* 2001). No tagged striped mullet were recorded near the base of the dam although juveniles of both species too small to be tagged were recorded in large numbers below the dam.

Downstream of Burrier

Changes in flow because of water extraction can lead to detrimental effects beyond the riverine system into adjacent marine coastal waters, which can affect commercial fishery operations (Gehrke *et al.* 1999). While commercial catch statistics are available for some of the economically important fish species, no data has been collected for the fish communities for the vast majority of NSW south coast estuaries (West and Jones 2001). In recent years, the adoption of the principles of Ecologically Sustainable Development (ESD) to fisheries and estuary management has meant that a much greater level of information concerning fish diversity in these estuaries is now required. Recognising this need, West and Jones (2001) conducted a three-year research program to provide information on the diversity and abundance of shallow water fishes in 24 NSW south coast estuaries, including the Shoalhaven River estuary. Shallow waters in NSW estuaries provide an important habitat for a variety of commercial fish species, and species recruiting in shallow waters also comprise the majority of the recreational catch in NSW waters (West and Jones 2001).

West and Jones (2001) sampled shallow water fish communities in the Shoalhaven estuary once during the summer and winter of the same year, at sites near the entrance. They found a substantial commercial fishery producing mainly finfish, prawns and oysters. Of the twenty-six fish species found in the area, twelve are considered of importance to commercial and recreational fisheries, among them are the yellow-finned leatherjacket (*Meuschenia trachylepis*), luderick (*Girella tricuspidata*) and tarwhine (*Rhabdosargus sarba*). The commercial fisheries production for the period 1995-06 was estimated at 133,000 kg per year.

Relationship between river flows and commercial fish catches

Information from commercial fish catches has previously been investigated in terms of the relationship to flow variables (The Ecology Lab 1996). This study did not find any relationships between river flows and catches of school prawns and king prawns in the Shoalhaven estuary. Another study done in 2002 into the relationships between river flows and commercial fish catches in the Hawkesbury and Shoalhaven estuaries (IEP and NSW Fisheries 2003) found the commercial catch in the Shoalhaven estuary was dominated by sea mullet, luderick and school prawn, accounting for 24%, 23% and 12% of the total catch respectively. Reported catches of 75% of the dominant species in the Hawkesbury estuary and 70% of dominant species in the Shoalhaven showed a significant relationship with river hydrology. However, catches of approximately 40% of the fish species dominant in the Hawkesbury and Shoalhaven estuaries showed a positive significant relationship with higher flow aspects of river hydrology. In contrast, the remaining species, including luderick, tailor, blue swimmer crab, sea mullet and squid either showed a positive response to low flow hydrological variables or negative responses to higher flow variables. Bream, school prawns and silver biddy generally showed the same response to the flow regimes in both estuaries, while luderick, mulloway and sea mullet showed differing responses between the two estuaries. Although the study demonstrated a relationship between reported commercial catches and various flow components, there remains uncertainty around which aspects of the hydrological regime influenced each species because the majority of hydrological variables are highly correlated.

Australian bass

The Australian bass (*Macquaria novemaculeata*) is considered in detail here because of the importance of this species as a top predator in the food web of the Shoalhaven system. This is also the species on which the original environmental flow recommendations of 90 ML/day were based and it is an iconic species in terms of recreational fishing. Australian bass are catadromous, migrating from freshwaters downstream to estuaries to breed from May to August before their return upstream (Harris and Rowland 1996) ('catadromous' fish migrate from freshwater to saltwater to spawn or reproduce). Female fish spawn in brackish waters in salinities one-third to half that of seawater and fish larvae metamorphose when fish are between 25 and 30 mm in length. Young fish reach about 100 mm in their first year. Harris (1986) suggested that the reproductive success of Australian bass in any year is controlled by river flow during the breeding season. During years of low river flow, Harris (1986) suggested that most female fish do not migrate to the estuary to spawn and consequently there is little or no recruitment in dry years.

A study by Growns (2003) showed that the percentage of young-of-year Australian bass and the catch of fish per unit effort is influenced by either the flow occurring in the same year and/or flow in the previous year. The number of Australian bass caught per unit effort during a bass catching event was positively associated with the median daily discharge and the number and duration of high flow events occurring in the previous year. The percentage of young-of-year Australian bass caught in any one year was positively associated with the median flow in the year of capture. In addition the percentage of these fish was positively associated with the maximum, mean and variation of daily flows, the number and duration of high flow events and the greatest rise and fall of daily flows in the previous year. Therefore, it can be concluded that the successful recruitment of Australian bass is dependent on floods, although it is difficult to say which hydrological variable is most important because of the high correlation of flood related variables.

Australian bass has a marked flexibility in its diet, reproduction and growth, is highly fecund and can live up to 22 years (Harris 1987) ('fecund' species have a high reproductive output based on when and how often they reproduce). These biological attributes enable Australia bass to survive in an environment that varies widely and unpredictably. The strong relationship between Australian bass recruitment and flow suggests that restoration of environmental flows will assist in the maintenance of populations of Australian bass in the Shoalhaven River system (Growns 2003). While the current 90 ML/day environmental flow release was based on the requirements of Australian bass, this may need to be reassessed because this flow was noted to be insufficient to cover riffles in some sections of the river by the Hawkesbury-Nepean River Management Forum Independent Expert Panel in 2003 (IEP 2003).

3.4.2 Macroinvertebrates

Macroinvertebrates are animals without backbones that are large enough to be visible with the naked eye, with examples including most aquatic insects, snails and crayfish. Baker *et al.* (2003; 2004) sampled several sites on a tributary of the Shoalhaven River in the headwater sections of the catchment above Tallowa Dam to assess the genetic diversity within four genera of macroinvertebrates ('genera' is the plural of 'genus', a collective term used to incorporate like-species into one group). They found extremely divergent lineages in all surveyed groups and evidence of cryptic species in three, identifying the upper catchment as a highly diverse area (‘cryptic species’ look identical to each other, but are actually different species). Linke and Norris (2003) also examined the macroinvertebrate biodiversity of sites in the Shoalhaven catchment, including sites further down the catchment but above Tallowa Dam. Most sites in the central Shoalhaven River catchment did not pass the condition assessment, highlighting a significant loss of macroinvertebrate diversity in this section of the catchment.

Some information is available in regard to the distribution, health and habitat requirements of macroinvertebrate communities downstream of Tallowa Dam, but more research is needed (Coysh *et al.* 2005).

Tallowa Dam to Burrier

The primary substrates downstream of Tallowa Dam are cobbles, boulders and bedrock (‘cobbles’ are water-worn rock fragments). At the time of the February 2003 field trip of the Hawkesbury-Nepean River Management Forum Independent Expert Panel (IEP 2003) the substrates were thickly coated in algal slimes, iron-manganese oxidising bacterium and associated detritus (‘detritus’ is dead or decaying organic matter). Small clumps of ribbon grass were also coated with these materials. The Independent Expert Panel concluded that it was highly likely that the cause of this coating was the release from the dam of bottom waters containing high levels of nutrients and other constituents, and that consequently habitat quality beneath the dam was considered to be highly degraded (IEP 2003). However, the prevailing drought conditions at the time would also have been a contributing factor.

The Independent Expert Panel considers that such low habitat quality beneath the dam is of considerable concern because fish and crustaceans migrating upstream would congregate in this area as they encounter passage blocks (riffles and the dam wall). Invertebrate food availability in this ‘migrant-waiting’ area would be expected to be low because the small spaces within the substrate would be sites of accumulation of decaying organic material. The decaying material in these spaces would result in depleted dissolved oxygen, thus restricting the lifecycle stages of many of the invertebrate species. (IEP 2003).

Surveying for macroinvertebrates in this section of the Shoalhaven River has been limited. In a survey of the Shoalhaven River by Sloane and Norris (1998) for the Healthy Rivers Commission, only one of the 8 sites sampled in the catchment was on the main arm of the Shoalhaven River. This site was assessed as being impaired by drought conditions (i.e. low flows). Norman and Turner (1999) report in their literature review that there was little information available on the macroinvertebrate communities of the Shoalhaven River apart from surveys done by The Ecology Lab between 1994 and 1998. Downstream of Burrier a total of 20 macroinvertebrate taxa were recorded, with Chironomidae (midges or gnats) the most abundant family, followed by Oligochaeta (worms), several gastropod species and the bivalve Corbiculina sp. also relatively abundant (‘gastropods’ are a class of mollusc that travel on a single, muscular foot and often secrete a one-piece shell for protection, for example snails; and ‘bivalves’ are molluscs that have two shells hinged together, for example mussels).

Based on the assemblages recorded, there appear to be fewer macroinvertebrate species downstream of Tallowa Dam than would be expected (Norman and Turner 1999).

Downstream of Burrier

There is limited macroinvertebrate data available for this section of the river. The Ecology Lab (1993a, 1993b) surveyed benthic (bottom dwelling) macroinvertebrates within 6 km upstream and downstream of the Shoalhaven Paper Mill. The fauna found was dominated by two species of bivalves and other species of molluscs, polychaetes (worms) and crustaceans. Another study undertaken by The Ecology Lab (1995) sampled benthic macroinvertebrates at two depths from Pig Island to Greenwell Point. In general, greater diversity of species and greater numbers of individuals were found closer to the mouth of the river, compared to sites further upstream. Polychaetes (worms) dominated the fauna, with bivalve molluscs also abundant. The data indicated that salinity, and to a lesser extent depth were the most important factors in explaining complex distribution patterns. A further study by The Ecology Lab (1996) identified 38 species of benthic macroinvertebrates. All of the species found were typical of estuarine fauna and none were considered rare or endangered. Considerable variation was observed in the patterns of distribution and abundance of the benthic macroinvertebrates across the study sites, and this was found to correlate strongly with variations in salinity.

Gillanders and Kingsford (2001) give a general overview of the macroinvertebrates commonly found in estuarine waters and limiting factors to their survival. They state that polychaetes (worms), molluscs and crustaceans dominate the benthic macroinvertebrates in saline areas of rivers and estuaries, but that knowledge of the effect of flow variability on macroinvertebrates is poor. Episodic salinity changes such as those associated with storms are likely to affect organisms in the top 2-3cm of natural sediment (Coull 1999).

3.4.3 Shellfish

Oysters are recognised as valuable integrative indicators of water quality in estuaries. Oysters are sedentary filter feeders that are estimated to filter between 0.5 - 1 ML of estuarine river water in the time they take to grow to market size (approximately 2 to 4 years) (White 2001). The abstraction of freshwater upstream during low flow periods constitutes a threat to growing healthy oysters, as does pollution from point and non-point sources (White 2001). Oyster embryos are markedly affected by acid sulphate soil drainage (Wilson and Hyne 1997), so concerns about potential acid sulphate soil drainage have been expressed by growers in the Shoalhaven (White 2001).

3.4.4 Other river dependent fauna

There are no studies specific to the Shoalhaven River to report in regard to other river dependent fauna such as platypus, turtles, water rats and frogs (Coysh *et al.* 2005). However, some studies are available that indicate flow requirements for the platypus and water rats.

A study by Grant and Bishop (1998) found that removing water from streams or increasing flows had the potential to impact on platypus populations. They proposed that a number of known habitat requirements of the platypus could be incorporated into a simple and practical rapid assessment methodology to make assessments of flow requirements for the species.

Scott and Grant (1997) reviewed the habitat requirements of both the platypus and water rat in relation to water management practices in the Murray-Darling basin. Low flow conditions over the cooler months were found to result in a reduction in foraging area for the platypus at a time when invertebrate abundance was also low. High flow conditions during the warmer months would flood many platypus burrows and reduce breeding success, and loss of condition could result from needing to expend more energy swimming against fast currents and in colder water. To overcome these problems, Scott and Grant (1997) recommended that:

- a minimum flow should be released through the winter months to cover riffle areas in order to increase invertebrate productivity, increase foraging area and facilitate movement through riffle areas without having to come out of the water; and

- extended periods of bankfull flow in late spring and summer should be avoided whenever possible.

The water rat was found by Scott and Grant (1997) to be an opportunistic species with a high degree of adaptability to conditions in a wide range of habitats.

3.4.5 Fauna habitat

The current environmental flow release has been noted to be insufficient to cover riffles in some sections of the Shoalhaven River downstream of Tallowa Dam (IEP 2003). The Hawkesbury-Nepean River Management Forum Independent Expert Panel (IEP 2004) alerts that the reduction of flows over riffles is a key issue, as it results in decreased habitat connectivity for mobile aquatic fauna along freshwater reaches and at the interface between freshwater and estuarine reaches. The species potentially adversely affected include fish, macroinvertebrates, platypus and turtles.

Additionally, altered river hydrology due to the presence and operation of Tallowa Dam could lead to modified habitat dynamics, for example the expansion or contraction of particular habitats and the increased stagnation of pools from reduced flushing flows. The increased stagnation of pools leads to reduced water quality, as does the release of bottom waters from the dam. The combined result of modified habitat dynamics and reduced water quality would be the loss of diversity in some faunal groups and the alteration of the structure of aquatic communities. (IEP 2004).

3.4.6 Aquatic macrophytes

Aquatic macrophytes are rooted and floating aquatic plants that are large enough to be visible with the naked eye.

Tallowa Dam to Burrier

Taylor-Wood (2002) surveyed the aquatic macrophytes in the reaches between Tallowa Dam and the ocean. In the section between Tallowa Dam and Burrier, immediately downstream of the dam, *Vallisneria gigantea* was observed growing in slower flowing pools but was not associated with the shallower, faster flowing areas. The water in these faster flowing areas was turbid, limiting the light availability for aquatic macrophytes. It was noted that the rocky bottom and limited availability of fine sediments in this reach were limiting factors for macrophyte growth. Further investigation is needed in this reach to determine the extent of aquatic macrophytes and the presence of exotic species (Taylor-Wood 2002) and how macrophyte distribution and abundance will respond to a new environmental flow regime (Coysh *et al.* 2005).

Downstream of Burrier

Taylor-Wood (2002) studied the aquatic macrophytes downstream of Burrier finding that they ranged from those found only in freshwaters to marine species. Immediately downstream of Burrier Weir, the dominant native freshwater species is *Myriophyllum* sp. Other species recorded include *Vallisneria gigantea*, *Potamogeton ochreatus*, *Chara spp*. and filamentous green algae. Two species of *Myriophyllum* were found to be abundant in still and less abundant in flowing waters. *Vallisneria gigantea* was only observed in still waters along with *Chara spp*. Algal biofilms were also observed on the rocks of the still pools. *Elodea canadensis* (a weed species) was recorded from within the weir pool and downstream of Burrier, which is a matter for concern and highlights the need for additional surveys to be undertaken between Tallowa Dam and Burrier to determine the extent of *Elodea canadensis* (and possibly *Egeria densa*) within the Shoalhaven River system. Downstream of Nowra Bridge, seagrasses were found dominated by *Zostera marina*. There are several areas of shallow sandbanks in the estuary that are covered by seagrasses (*Zostera marina and Halophila* sp.) providing important areas for fishes and waterbirds.

In December 1994 general patterns in the distribution of some aquatic plant species were recorded by The Ecology Lab (1996). Similar recordings were made during the traverse of the estuary in February 2003 by the Hawkesbury-Nepean River Management Forum Independent Expert Panel, and differences in the distribution of two key species of aquatic plants were observed. Ribbon grass (*Vallisneria* sp.), a freshwater associated submersed macrophyte that provides high quality sheltering habitat for fish and invertebrates during most tides, had reduced greatly in distribution. The common reed (*Phragmites australis*), a moderately salt tolerant emergent macrophyte that provides high quality sheltering habitat for fish and invertebrates during only middle to high tides, had increased greatly in distribution.

The Independent Expert Panel concluded that increased salinisation of the estuary was most likely to have caused these distributional changes, however as discussed in Section 3.3.3 there is currently uncertainty in regard to the salinity regime in the Shoalhaven River estuary and further investigation is needed.

3.4.7 Riparian vegetation

Vegetation mapping

The vegetation associations of the catchment have been mapped by Tindell *et al.* (2005) at 1:100,000 scale. Although not specifically mapping the riparian zones, data is available on the riparian (riverbank) vegetation downstream of Tallowa Dam where the vegetation extent is greater than 2 hectares.

Tallowa Dam to Burrier

Taylor-Wood (2002) describes the riparian vegetation in this reach as being a reflection of the predominant water levels and being primarily made up of casuarinas (*Casuarina cunninghamiana*) with little fringing vegetation, set back from the current river channel. Riparian vegetation encroachment as a result of reduced flows is a potential issue in this reach (Coysh *et al.* 2005). Encroachment promotes excessive shading of the river and reduces riparian vegetation diversity. There is an extensive distribution of the weed species lantana along the gorge (Coysh *et al.* 2005). The setback of riparian vegetation immediately below the dam is probably in response to high flow spills over the dam wall (Coysh *et al.* 2005).

Downstream of Burrier

Taylor-Wood (2002) observed riparian weed species growing within the river channel and lower on the shore, with native casuarinas present higher on the banks.

Downstream of Nowra Bridge, along the edges of the river and channel, mangroves and stands of *Phragmites* reed were also observed. However, there were only a few stands of natural riparian vegetation present, dominated by casuarinas. In this reach the riparian zone was badly degraded due to vegetation clearing, trampling by cattle and the presence of exotic species (Taylor-Wood 2002). This degradation has contributed to bank slumping and erosion. In addition, many of the lateral wetlands that were once present in this reach have been drained and in-filled. At the time of the survey, Shoalhaven Riverwatch and NSW Fisheries were carrying out mangrove rehabilitation along a considerable proportion of the foreshore.

3.4.8 Wetlands and waterbirds

Wetlands of the Shoalhaven estuary provide important bird habitat, with the area classified as one of the three most important waterbird areas in NSW and the Directory of Important Wetlands in Australia (Environment Australia 2001) listing 78% of the wetlands in the Shoalhaven catchment as important. A review of the distribution and conservation status of wetlands in New South Wales by Kingsford *et al.* (2004) identified wetlands as among the most threatened ecosystems in the world. The study identified that existing inventories of wetlands are poor, mainly because few adequately define their objectives, provide explicit (and hence repeatable) methodology or are publicly accessible.

Kingsford *et al.* (2004) classified 1% of the total area of the Shoalhaven catchment as wetland. Of the wetland area of 4465 hectares, <1% was classified as freshwater lake, 67% was classified as estuarine wetland, 15% was classified as coastal lagoons and lakes and 17% was classified as floodplain wetland. The Shoalhaven catchment was also found to be highly regulated, with Kingsford *et al.* (2004) identifying the 48 weirs in the catchment as a major threat to downstream floodplain wetlands.

Changes in flow may affect waterbirds, especially species that feed on plants, frogs and fish. The diversity of waterbirds is dependent on the diversity of habitats within and among systems of wetlands, so alterations to natural fluctuations of water level may alter habitats and in turn assemblages of birds (Brock *et al.* 1999). Unlike other taxa, birds are able to move as areas dry up (Gillanders and Kingsford 2001).

Most of the Shoalhaven River estuary wetlands have been adversely affected by reduced flooding as a result of flood mitigation and drainage works on the Shoalhaven River floodplain (IEP 2004).

3.5 Flow-ecology relationships

The widespread concern about the downstream impacts of dams is based on the logical assumption that river ecology and river geomorphology depend on the volume and timing of downstream flows. A CRC for Freshwater Ecology review of Australian and international literature found indisputable evidence to support this assumption (Lloyd *et al.* 2003). However, the review also found that the relationship between the degree of flow modification and ecological or geomorphological change is not simple. A direct relationship between flow modification and ecological and geomorphological change might be expected, where a small flow modification results in small changes and a large flow modification results in large changes. Instead, the review found that severe changes can occur in response to even small alterations to flow. For example, the lowest proportional hydrological change recorded in the reviewed literature (29%) was associated with the loss of 67% of a grassland ecosystem, and a proportional hydrological change of only 33% at a weir was associated with 72% fewer birds' nests at a downstream swamp and lake.

Only a few studies examined in the CRC for Freshwater Ecology review of Australian and international literature provided quantified information on flow change and ecological and geomorphological response that could be compared between studies and included in analyses of relationships and thresholds (Lloyd *et al.* 2003). The CRC for Freshwater Ecology also drew a similar conclusion when reviewing studies relating to the Shoalhaven River downstream of Tallowa Dam, finding that studies conducted so far have not been designed to detect the responses of the ecology to changes in flow brought about by dam operation (Coysh *et al.* 2005).

In the absence of studies directly examining the relationship between flow modification and ecological and geomorphological change, it can be difficult to determine the effect of a new environmental flow regime as rivers are complex systems and are influenced by many interacting biological and human factors (Coysh *et al.* 2005). The Multiple Levels and Lines of Evidence (MLLE) approach is proposed as a logical way of organising evidence to be able to infer cause and effect (Cottingham *et al.* 2005). MLLE has only started to be formally adopted in ecology (Beyers 1998; Downes *et al.* 2002), however, it has been employed extensively and successfully in epidemiology; a field that, like environmental assessment, also faces difficulties demonstrating cause and effect. In the MLLE framework (Cottingham *et al.* 2005):

- A *line of evidence* is a type of evidence, such as an ecosystem attribute (e.g. fish abundance, macroinvertebrate species richness, macrophyte biomass), that is investigated in relation to a stressor or intervention; and
- A *level of evidence* is a strength-of-evidence value used to determine the case for inferring that a given human activity causes a given ecological or geomorphological change.

The CRC for Freshwater Ecology assessed the available literature using the MLLE approach to assist in the determination of environmental flows for the Shoalhaven River downstream of Tallowa Dam (Coysh *et al.* 2005). An initial literature review identified seven lines of evidence which were used in the assessment, being fish, macroinvertebrates, periphyton/algae, water quality, geomorphology, riparian vegetation and platypus. An intensive, but necessarily limited, search of Australian and international scientific literature was subsequently conducted. In total 39 scientific papers, selected from several hundred, were entered into specially developed MLLE software which was then used to test the following questions:

1. Could a reduction in *flow variability* have a significant ecological impact on the Shoalhaven River downstream of Tallowa Dam?
2. Could a reduction in *flow volume* have a significant ecological impact on the Shoalhaven River downstream of Tallowa Dam?
3. Could the *temperature* of water released from Tallowa Dam have a significant ecological impact on the Shoalhaven River downstream of the release site?

Only questions concerning ecological impacts were tested, as the MLLE assessment found that none of the studies assessing geomorphology could be used. This may be because, as a geological process, geomorphology generally takes longer than biological processes to respond to change, and is therefore difficult to study rigorously. The CRC advises that while geomorphology may be an important component of ecosystem function, the length of time needed for its study means that it may be more feasible to examine other equally important lines of evidence when developing an environmental flow regime.

The results of the MLLE assessment were:

1. Few scientific papers were found concerning the effects of a reduction in flow variability, and these papers offered little support for determining if a reduction in flow variability has a negative ecological effect.
2. Many papers were found that demonstrated an ecological response to changes in flow volume. The strongest lines of evidence were fish and macroinvertebrates.
3. Some papers were found that were relevant to the question of whether temperature changes downstream of dams have an effect on stream ecology. However, the evidence provided by these was not strong.

The MLLE assessment suggests that investigating fish and macroinvertebrates would provide ecological information about the impact of flow volume in which considerable confidence could be placed. Additionally, if fish were chosen they would provide further information about a group that has been identified as both socially and economically important in the region. It is likely both groups may be important because they respond to different environmental features and timescales, invertebrates over shorter timescales and fish to longer ones.

3.6 Adaptive management

3.6.1 The Precautionary Principle

A considerable amount of knowledge is available to assist the determination of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam, and further information will be revealed by current investigations. However, because the science of environmental flows is relatively new, the knowledge base is incomplete.

The Precautionary Principle, part of the Declaration of the United Nations Conference on Environment and Development, advises that lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation (UNEP 1992). This means that a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam should be implemented because the available knowledge clearly shows that improvements can be made to the current situation. The *Guidelines for Applying the Precautionary Principle to Biodiversity Conservation and Natural Resource Management* (The Precautionary Principle Project 2005) recommend that an adaptive management approach is particularly useful in the implementation of the Precautionary Principle, as full scientific certainty about management measures is not required before implementation. The adaptive management approach involves implementing such measures as part of rigorously planned and controlled programs, with careful monitoring and periodic review to provide feedback, and then subsequent adaptation of management measures in the light of review results and new information.

The following subsections present the CRC for Freshwater Ecology recommendations in regard to an adaptive management process for environmental flows for the Shoalhaven River downstream of Tallowa Dam (Coysh *et al.* 2005).

3.6.2 The adaptive management process

Adaptive management requires river management authorities to be flexible in their approaches to issues that are highly complex, inter-related and involve multiple stakeholders. This requires a capacity to respond to feedback and apply new learning obtained through an assessment program to help build relationships between decision makers and stakeholders (IEP 2004). Adaptive management requires making decisions to achieve desired objectives, assessing the nature of the outcome and using the evidence garnered from assessment to affirm, or modify the management decision.

Earlier approaches to arrest the decline of native fish populations in the Murray-Darling Basin are an example of adaptive management at work. The focus was on inundation of river red gum forests in floodplain habitats, as these were believed to be important nursery habitats for fish recruitment before river regulation. However, more recent studies revealed that under current regulated flow conditions the small-scale inundation of these habitats does not provide suitable conditions for native fish. Therefore, it was necessary to identify productive habitats for fish under current river conditions and to characterise the key factors associated with native fish communities to enable river managers to provide flows to improve native fish communities. This example highlights the need to use information and make decisions in an adaptive management context and to focus on the ecological outcomes it is intended to achieve.

Adaptive management involves the review of scientific information that has been specifically designed to enable environmental flow decision-makers to evaluate the effectiveness of previous decisions and 'adapt' future decisions. The best outcomes are achieved when the process is set up to allow the people who generate the scientific information to have independence from the decision-makers. This reduces the risk of inadvertent bias in the decision-making and helps to keep the focus on the outcomes of the science rather than on how the science was done. There is also a need for properly designed studies (with controls or reference sites if possible) to provide baseline information before changes to the flows are made.

3.6.3 Objectives and indicators

The initial step in the adaptive management process for a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam is to establish key ecological objectives. Assessment is subsequently carried out to determine if these key ecological objectives are being met.

Maintaining or improving the health of the ecology and ecological processes of the Shoalhaven River downstream of Tallowa Dam is the main purpose of implementing a new environmental flow regime. Because of this, decisions need to be made in regard to the species, ecological communities or ecological processes that will be targeted for assessment to determine if key ecological objectives are being met. Decisions about what will be targeted should be made at the outset, but can be modified later if necessary through the adaptive management process. To make these decisions, the following questions need to be answered:

1. What species, ecological communities or ecological processes will be targeted, and what is their relationship to the environmental flow regime?
2. What are the key ecological objectives for each?
3. What is the current distribution and abundance of target species, the current health of target ecological communities and the current state of ecological processes?
4. What key information on the ecology of species and their habitat requirements still needs to be collected to inform decisions in regard to a new environmental flow regime?
5. What environmental flow regime will achieve the key ecological objectives for the target species, ecological communities and ecological processes?

It may not be practical or possible or indeed necessary to measure all the species, ecological communities or ecological processes for which there are key ecological objectives. Indicator species or groups can instead be utilised, where a smaller subset of all of the species and groups is identified and used to indicate the condition of the overall river environment and the status of other species and groups in the river environment. Some considerations for the choice of indicators include:

- select indicators that are indicative of the wider range of ecological processes and broader ecological health that is being assessed;
- select indicators that are responsive to the proposed management interventions, and that will respond in appropriate timescales;
- select indicators that are relatively easy to measure; and
- consider indicators that also have important social and/or economic meaning.

The Multiple Lines and Levels of Evidence (MLLE) assessment has identified that for determining effects related to flow volume, most support in the literature is available for fish and macroinvertebrates. Both of these groups would make suitable indicators according to the above considerations. Fish are a top-level predator and contribute to important ecosystem processes, they respond to flow (although on longer timeframes of 3-5 years), they are relatively easy to measure and have both social and economic importance. Macroinvertebrates are also indicative of a range of processes, will respond to changes in flow volume (and on much shorter timeframes than fish) and are also easy to measure, although they are generally not considered socially or economically important.

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4. Conclusions

4.1 Conclusions of the knowledge review

The conclusions of the knowledge review are summarised below, and the knowledge gaps identified in the knowledge review are summarised in the next section.

4.1.1 Fluvial geomorphology

Geomorphological setting

Geomorphological studies of the Shoalhaven River have identified three distinct river reaches downstream of Tallowa Dam:
- confined valley with discontinuous floodplain between Tallowa Dam and Burrier (freshwater river reach);
- bedrock controlled tidal zone between Burrier and Nowra (upper estuary); and
- tidal coastal plain between Nowra and the ocean (lower estuary).

Conceptual models developed for the three reaches illustrate the key characteristics of each reach and introduce the potential impacts of Tallowa Dam.

Sediment transport

A lack of significant sediment cover over the steeply sloping continental landscape of southern NSW has resulted in a comparatively low rate of sediment supply to the lower Shoalhaven River. Additionally, Tallowa Dam now acts as a sediment trap. However, the sediment loading of the Shoalhaven River appears to increase downstream of the confluence of Yalwal Creek and the Shoalhaven River.

Acid sulfate soils

Acid sulfate soils are found on the Shoalhaven floodplain. However, the floodplain reach of the river is dominated by tidal processes, and flood mitigation works on the floodplain mean that only the largest freshwater river floods can now reach the acid sulfate soils. Because of this, changes to the hydrology of the Shoalhaven River as a result of Tallowa Dam and associated transfers are unlikely to be a driving factor for acid production on the floodplain.

4.1.2 Hydrology

Water extractions

Shoalhaven City Council extracts water from the Shoalhaven River at Burrier, and the SCA can transfer water from Tallowa Dam to the Hawkesbury-Nepean River System.

There are also a number of other licensed water users downstream of Tallowa Dam. The amount of water used is small compared to Shoalhaven City Council's extractions and the SCA's transfers. In addition, landowners with a direct river frontage are permitted to extract water for domestic purposes and stock watering. As this water is extracted under one of three types of Basic Landholder Rights in the *Water Management Act 2000*, there is no record of the amount of water extracted.

Discharges

As well as the range of extractions, there are discharges of wastewater into the Shoalhaven River estuary from several sources. The amount of water discharged is small compared to the overall amount of water extracted.

Impact of water transfers on river flow

Since 1980, water has been transferred from Tallowa Dam to the Hawkesbury-Nepean River System during three periods of drought. This has had a negative impact on low flows in the Shoalhaven River. Overall, the water transfers have had little impact on moderate and high flows along the Shoalhaven River.

Groundwater

The Shoalhaven River catchment is not noted for its groundwater resources, however there is some concern that extraction of groundwater from the headwaters of the Kangaroo River may impact on base flows in the river system.

The Shoalhaven River floodplain has relatively high water tables, with ground water being brackish to saline. Groundwater flows in the floodplain are unknown.

4.1.3 Water quality

Impacts of dam stratification

The current layout and numbers of monitoring sites between Tallowa Dam and the ocean is insufficient to fully determine the effects of the dam or dam operations on water quality in the Shoalhaven River. However, despite the inadequacy of current monitoring and analysis of water quality, it is clear the river downstream of the dam has been negatively impacted by dam releases that have been cold and low in quality. Tallowa Dam has had the effect of suppressing water temperature in summer and spring, and elevating water temperature in winter. The temperature suppression in summer and spring has been a result of the release of cold water from outlets in the dam wall 20 metres below the spillway crest when the dam is stratified.

At Grassy Gully, 20 km downstream of Tallowa Dam, the suppressed temperature recovers to approximately the same temperature as the Shoalhaven River above Lake Yarrunga. However, it has not been possible to determine exactly how far downstream from the dam the cold water pollution has been extending as there are currently no other monitoring sites between Tallowa Dam and Grassy Gully.

Stratification of the water column in Tallowa Dam can also lead to the release of iron, manganese and aluminium from bottom sediments into the water column which, if discharged from the dam, can lead to similarly increased concentrations of these elements in downstream waters. Iron precipitate and iron-oxidising bacteria have been particularly evident in the Shoalhaven River immediately downstream of the dam, and monitoring data indicates that elevated concentrations of iron have been present. The implications of this are the direct loss of both native plants and animals or the loss or simplification of habitat.

As a pilot measure to address stratification, the SCA recently installed a compressor and aeration system in Lake Yarrunga to mix warmer surface water with the cooler deeper water. The SCA will study the downstream environment to monitor changes resulting from the system. A multilevel offtake, which would allow water to be released from different levels in the lake, is also being considered.

Estuary salinity

There is currently uncertainty in regard to the salinity regime in the Shoalhaven River estuary and the impact of freshwater extractions on that regime. An examination of Shoalhaven River estuary salinity in 2003 concluded that the low salinity zone of the estuary had been greatly compressed, and water extractions were identified as a potential contributor to this compression. Different conclusions were drawn in hydrological investigations completed in 1996 for Shoalhaven City Council. These investigations found that the Shoalhaven River estuary was dominated by tidal processes, and that high freshwater short-term events only had a short temporary effect on the salinity regime in a small section of the upper estuary.

In addition to the possible compression of the low salinity zone of the estuary, freshwater extractions could be changing the variability of the salinity regime or reducing the volume or frequency of flushing flows. The impact of freshwater extractions on salinity variability may be ecologically significant for the Shoalhaven.

Stratification of natural pools

As well as occurring in dams, stratification can occur in the deep pools that occur in river systems. Stratification of the deep pools in the Shoalhaven River downstream of Tallowa Dam can occur naturally. However, the frequency, duration and magnitude of stratification events could be exacerbated by prolonged low flows caused by transfers from Tallowa Dam to the Hawkesbury-Nepean River System. Stratification can have significant impacts on both water quality and pool-dependent plants and animals. High freshwater short term events in river systems, in particular flood flows, help to mitigate the effects of stratification by flushing out deep pools with fresh water.

Other water quality issues

Another potential water quality problem is the risk of the downstream release of the high levels of cyanobacteria (blue-green algae) that have been recorded in the Kangaroo Arm of Lake Yarrunga. However, this risk has already been addressed in SCA's Water Management Licence.

4.1.4 Ecology

Fish

The best biological data available for the Shoalhaven River downstream of Tallowa Dam is in regard to fish due to the presence of numerous species of commercial and recreational interest. The Shoalhaven River has special significance for fish conservation because it has provided permanent habitat for the Australian grayling, which is listed as vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and protected in New South Wales and Victoria.

The distribution of many native fish in the Shoalhaven River has been affected by the physical presence of Tallowa Dam, which acts as a barrier to fish migration. Native fish species can also be affected by the associated effects that dam operations have on flow, water quality and physical habitat; with some freshwater species found to be sensitive to changes in flow. A relationship between commercial fish catches and Shoalhaven River flow has been found, however there remains uncertainty around which aspects of the flow regime influenced each species. The SCA is proposing to construct a fish passageway to address the barrier to fish migration currently presented by the Tallowa Dam wall.

The Australian bass has been a focus of interest in the Shoalhaven River because it is a top predator in the food web of the river system and an iconic species in terms of recreational fishing. This is the species on which the original provisional environmental flow recommendations were based, however this may need to be reassessed because this flow has been observed to be insufficient to cover riffles in some sections of the river.

Macroinvertebrates

Some information is available in regard to the distribution, health and habitat requirements of macroinvertebrate communities downstream of Tallowa Dam. Based on the assemblages recorded, there appear to be fewer macroinvertebrate species in the freshwater reach downstream of Tallowa Dam than would be expected. Further downstream in the Shoalhaven River estuary, observed variation in the patterns of distribution and abundance of macroinvertebrates was found to correlate strongly with variations in salinity.

Other river dependant fauna

Limited information is available on other river dependent fauna such as platypus, turtles, water rats and frogs.

Fauna habitat

The current provisional environmental flow release has been observed to be insufficient to cover riffles in some sections of the Shoalhaven River downstream of Tallowa Dam. The reduction of flows over riffles is a key issue, as it can result in decreased habitat connectivity for mobile aquatic fauna along the freshwater river reach and at the interface between the freshwater reach and the estuary. The species potentially adversely affected include fish, macroinvertebrates, platypus and turtles.

Additionally, altered river hydrology due to the presence and operation of Tallowa Dam could lead to modified habitat dynamics, for example the expansion or contraction of particular habitats and the increased stagnation of pools from reduced flushing flows. This would contribute to a loss of diversity in some faunal groups and the alteration of the structure of aquatic communities.

Aquatic macrophytes and riparian vegetation

In the estuarine section of the river, changes to aquatic macrophytes and riparian vegetation are believed to be a response to increased salinisation of the estuary under low flow conditions. The setback of riparian vegetation immediately below the dam is probably in response to high flow spills over the dam wall. Further down the river, riparian vegetation is encroaching on the channel as a result of reduced flow in drought conditions. Introduced species and degradation of the riparian zone by cattle are problems in the lower reaches of the river.

Wetlands and waterbirds

Wetlands of the Shoalhaven River estuary are classified as one of the three most important waterbird habitats in NSW, and the Directory of Important Wetlands in Australia lists 78% of the wetlands in the Shoalhaven catchment as important. Most of the estuary wetlands have been adversely affected by reduced flooding as a result of flood mitigation and drainage works on the Shoalhaven River floodplain.

4.1.5 Flow-ecology relationships

The CRC for Freshwater Ecology assessed the available literature using the Multiple Lines and Levels of Evidence (MLLE) approach to assist in the determination of environmental flows for the Shoalhaven River downstream of Tallowa Dam. Only ecological impacts were examined, as the MLLE assessment found that none of the studies assessing geomorphology could be used. While geomorphology may be an important component of ecosystem function, the length of time needed for its study means that it may be more feasible to examine other equally important lines of evidence when developing an environmental flow regime.

The results of the MLLE assessment were:
1. Few scientific papers were found concerning the effects of a reduction in flow variability, and these papers offered little support for determining if a reduction in flow variability has a negative ecological effect.
2. Many papers were found that demonstrated an ecological response to changes in flow volume. The strongest lines of evidence were fish and macroinvertebrates.
3. Some papers were found that were relevant to the question of whether temperature changes downstream of dams have an effect on stream ecology. However, the evidence provided by these was not strong.

The MLLE assessment suggests that investigating fish and macroinvertebrates would provide ecological information about the impact of flow volume in which considerable confidence could be placed.

4.1.6 Adaptive management

The Precautionary Principle advises that lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation, meaning that a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam should be implemented because the available knowledge clearly shows that improvements can be made to the current situation.

An adaptive management approach is particularly useful in the implementation of the Precautionary Principle, as full scientific certainty about management measures is not required before implementation. The adaptive management approach involves implementing such measures as part of rigorously planned and controlled programs, with the periodic review of scientific information that has been specifically collated to enable environmental flow decision-makers to evaluate the effectiveness of previous decisions and ‘adapt’ future decisions.

Maintaining or improving the health of the ecology and ecological processes of the Shoalhaven River downstream of Tallowa Dam is the main purpose of implementing a new environmental flow regime. As a result, decisions need to be made in regard to the species, ecological communities or ecological processes that will be targeted for assessment to determine if key ecological objectives are being met. Decisions about what will be targeted should be made at the outset, but can be modified later if necessary through the adaptive management process.

In the adaptive management framework, assessment is required to determine if the key ecological objectives are being met. It may not be practical or possible or indeed necessary to measure all of the ecological processes or organisms for which there are key ecological objectives. Indicator species or groups can instead be utilised, where a smaller subset of all of the species and groups is identified and used to indicate the condition of the overall river environment and the status of other species and groups in the river environment. The Multiple Lines and Levels of Evidence (MLLE) assessment identified that for determining effects related to flow volume, most support in the literature is available for fish and macroinvertebrates.

4.2 Summary of knowledge gaps identified by the knowledge review

The knowledge gaps identified through the knowledge review are summarised below.

4.2.1 Fluvial geomorphology

Sediment transport

Tallowa Dam is known to have had an impact on sediment supply to the lower Shoalhaven River, but the extent of this impact is not known. More information is required on sediment transport processes, the impacts of Tallowa Dam on these processes, and the role of environmental flows in these processes. This information will help to identify how sediment supply and channel processes will respond to a new environmental flow regime, with channel geomorphology having an important role in determining habitat availability for various river organisms.

4.2.2 Hydrology

Flow modelling

Most of the flow modelling for the Shoalhaven River downstream of Tallowa Dam has been based on monthly flow data. However, the Shoalhaven River experiences extreme variability in flow, with flows often changing from one day to the next. This means that models based on daily or even hourly flow data are required to facilitate an accurate determination of the amount of water required to provide suitable species habitat and a better understanding of the aspects of the flow that are important for the health and reproduction of various species.

Water extractions

The exact volume of water extracted for Basic Landholder Rights downstream of Tallowa Dam should be determined as these extractions affect the actual amount of water received by the environment.

Groundwater

More information on groundwater is desirable as the interaction of groundwater with the river can affect river hydrology and ecology.

4.2.3 Water quality

Monitoring and analysis of water quality

Current monitoring and analysis of water quality downstream of Tallowa Dam is limited in its ability to detect the current extent of dam impacts or the future effects of a new environmental flow regime. The monitoring and analysis is inadequate in terms of the number of monitoring sites and their location, the variables that are measured, and the study design. There is also a lack of analysis of water quality data in terms of its relationship to ecology, and more focussed monitoring is needed of variables and indicators relevant to ecological outcomes.

Estuary salinity

Further investigation is needed to resolve uncertainty in regard to the salinity regime in the Shoalhaven River estuary, the impact of freshwater extractions on that regime and the effects of an environmental flow on that regime. This should involve detailed numerical modelling of the estuary, carried out in association with examining the inflow/salinity responses of estuarine plants and animals that are sensitive to changes in salinity.

Other water quality issues

Further investigation is needed into the impact of flows and particularly flushing flows on water quality and the relationship between flow and the transport of organic matter and nutrients down the river.

4.2.4 Ecology

Macroinvertebrates

Most of the macroinvertebrate sampling conducted to date has been undertaken in the upper part of the catchment, with only limited sampling below the dam. Previous sampling has not been designed to detect changes along the river due to the presence of the dam, and as a result little is known about the effect of the dam or water transfers on macroinvertebrate communities and how far downstream these effects may extend. There has also been limited use of macroinvertebrate data for assessing ecosystem condition, as so far most analysis has focussed on describing community composition, distribution and abundance.

Other river dependant fauna

More information is needed on the current distribution, abundance, condition, habitat preferences and flow responses of other river dependent fauna such as platypus, turtles, water rats and frogs.

Aquatic macrophytes and riparian vegetation

Further investigation is needed to determine the extent of aquatic macrophytes, the presence of exotic species, and the response of aquatic macrophytes to a new environmental flow regime.

Wetlands and waterbirds

There is little information available on waterbirds, and existing knowledge of wetland condition is also poor. Because of the flood mitigation and drainage works that have occurred on the Shoalhaven River floodplain, environmental flows are unlikely to be able to assist any of the riverine or floodplain wetlands. However, further investigation is needed.

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5. Glossary

Anoxic. An absence of dissolved oxygen in water. The incidence of anoxic (absence of oxygen) and hypoxic (low in oxygen) events is a suggested water quality indicator in the ANZECC/ARMCANZ water quality guidelines, and was adopted as an indicator of ecosystem integrity during the National Land and Water Resources Audit.

Aquatic macrophytes. Rooted and floating aquatic plants that are large enough to be visible with the naked eye.

Bedload. Sediment or other material that is carried by a water current along the floor or bed of a river, stream or watercourse.

Benthic. Aquatic organisms that live on the bottom of a river, lake or ocean.

Catadromous. Fish that migrate from freshwater to saltwater to spawn or reproduce.

Chlorophyll-*a*. A green pigment found in plants that absorbs sunlight and converts it to sugar during photosynthesis. Chlorophyll-*a* concentrations are an indicator of phytoplankton abundance and biomass in coastal and estuarine waters and are a commonly used measure of water quality. High levels often indicate poor water quality and low levels often suggest good conditions. However, elevated chlorophyll *a* concentrations are not necessarily a bad thing; it is the long term persistence of elevated levels that is a problem.

Cobbles. Water-worn rock fragments.

Diadromous. Organisms that migrate between fresh and salt water during their life cycle.

DIPNR. NSW Department of Infrastructure, Planning and Natural Resources.

DLWC. NSW Department of Land and Water Conservation.

DNR. NSW Department of Natural Resources.

Fecund. Species that have a high reproductive output based on when and how often they reproduce.

Fluvial geomorphology. The study of river processes and form.

Geomorphology. The study of landforms and the processes that form them.

GL. A gigalitre, where 1 gigalitre = 1 billion litres = 1,000,000,000 litres.

Hydrology. The study of the properties, distribution, and circulation of water on the surface of the land, underground, and in the atmosphere.

Macroinvertebrates. Animals without backbones that are large enough to be visible with the naked eye. Examples include most aquatic insects, snails and crayfish.

Macrophytes. Plants that are large enough to be visible with the naked eye.

ML. A megalitre, where 1 megalitre = 1 million litres = 1,000,000 litres.

ML/day. A flow rate measured in megalitres per day, where
1 megalitre per day = 1 million litres per day = 1,000,000 litres per day.

Periphyton. Algae that are attached to rocks or other aquatic substrates.

Phytoplankton. Microscopic aquatic plants, for example algae.

Polychaetes. A class of marine worms and their free-swimming larvae.

Riffle. A shallow area of a river or stream where water flows rapidly over a gravel or rocky stream bed, marking the point of inflection (the cross-over of energy line) between two bends of a channel. Riffle spacing is often from 5 to 7 times the channel width and their locations are semipermanent. They are very important in stream ecology.

Riparian. Relating to, or living or located on, the bank of a watercourse (usually, but not always, a river or stream).

SCA. Sydney Catchment Authority.

Stratified, Stratification. The development of distinct layers of different temperature, density and water quality at various depths in a dam, with a restriction of mixing throughout the water column. During winter and early spring, most dams are well mixed throughout their water column. Thermal stratification develops in late spring or summer when the upper layers of the dam are heated by solar radiation faster than the heat can disperse into the lower depths of the dam. The difference in the density of the surface and bottom layers retards mixing within the water column and can lead to the top and bottom layers having significantly different water qualities.

Turbid, Turbidity. The cloudy appearance of water caused by the presence of suspended particles.

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