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Shoalhaven Environmental Flows
Scientific Advisory Panel

Environmental water requirements for the Shoalhaven River estuary

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This Discussion Paper has been prepared by the NSW Government Department of Natural Resources to assist the development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam.

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Executive Summary

Shoalhaven River environmental flows Estuary Modelling and Assessment investigation

The NSW Department of Natural Resources (DNR) is coordinating the development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam, with a view to having a recommended regime ready for Government consideration at the end of 2006.

The development of the new environmental flow regime involves the following steps:

1. *Knowledge review* - Compilation and analysis of previous knowledge to provide an understanding of the Shoalhaven River downstream of Tallowa Dam, identify the known effects of the dam and its operation 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.

The knowledge review step was completed in 2005. From the conclusions of the knowledge review and the advice of specialists in NSW Government agencies, the following investigations were initiated:

1. Hydrologic (Flow) Analysis and Modelling.
2. Physical and Ecological Investigations:
    - Water Quality Assessment;
    - Thermal Regime Assessment;
    - Flora and Fauna Review;
    - Aquatic Invertebrates Study;
    - Physical Habitat Modelling;
    - Fish Passage Study; and
    - Estuary Modelling and Assessment.
3. Social, Economic and Cultural Heritage Assessments.

This paper discusses the Estuary Modelling and Assessment investigation.

One of the other investigations being carried out as part of the process for the development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam is the Flora and Fauna Review investigation. The aim of the Flora and Fauna Review is to better understand the relationships between river flow and the flora and fauna species and communities that occur in, or rely upon, the Shoalhaven River downstream of Tallowa Dam, including the Shoalhaven estuary and riparian (riverbank) habitats. The Flora and Fauna Review investigation is closely associated with the Estuary Modelling and Assessment investigation. A report on the Flora and Fauna Review investigation will be available later in 2006.

The Estuary Modelling and Assessment investigation also has an association with the Shoalhaven River Estuary Management Plan which is currently being prepared for Shoalhaven City Council.

Please see Sections 1.1 and 1.2 of this paper for further information on the development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam, the Estuary Modelling and Assessment investigation, the Flora and Fauna Review investigation, and the Shoalhaven River Estuary Management Plan.

A methodology for investigating environmental flows for the Shoalhaven River estuary

The Estuary Modelling and Assessment investigation has used a methodology developed through the Environmental Flows Initiative of the National River Health Program. The methodology is described in the Environmental Flows Initiative report, 'Environmental Water Requirements to Maintain Estuarine Processes' (Peirson *et al.* 2002), and is composed of two phases: a 'Preliminary Evaluation Phase' and a 'Detailed Investigative Phase'.

The Preliminary Evaluation Phase aims to yield a classification of estuaries by significance and risk as well as the scope of more detailed investigative programs. The purpose of the Detailed Investigative Phase is to determine an appropriate level of environmental freshwater flow for any given estuary.

The methodology is introduced in Section 1.3 of this paper.

Application of methodology; conclusions and recommendations

The Preliminary Evaluation Phase of the methodology has been carried out for the Shoalhaven River estuary. The results of the Preliminary Evaluation Phase are documented in Section 2.1 of this paper, and include:

- an explanation of the environmental flow issue that is being investigated (for further information see Section 2.1.1);
- a values assessment of the Shoalhaven River estuary (for further information see Section 2.1.2);
- an assessment of inflow variables for the Shoalhaven River estuary, changes due to human activity, and the magnitude of these changes (for further information see Section 2.1.3); and
- an assessment of the vulnerability of the valued components of the Shoalhaven River estuary to a range of potential inflow-reduction processes (for further information see Section 2.1.4).

From these results, recommendations for the scope of the Detailed Investigative Phase for the Shoalhaven River estuary are made, as discussed in Sections 2.2 and 2.3 of this paper. The recommendations are:

A. That new flow and salinity modelling of the Shoalhaven River estuary, as required in Step 1 of the Detailed Investigative Phase, is essential to resolve the current lack of clarity in regard to the salinity regime in the Shoalhaven River estuary and the impacts of current and proposed increased water transfers on that regime. The new modelling needs to be carried out in association with examining the inflow/salinity responses of ecological indicators, and should investigate the impact of freshwater extraction on the low salinity zone of the estuary, on the variability of the salinity regime and on the volume and frequency of flushing flows. The modelling should use the new bathymetric (river bed) data being compiled in 2005-2006 by DNR. For further information see Section 2.2.1.

B. That the Detailed Investigative Phase considers the vulnerability of Australian Grayling eggs and hatchlings to altered estuary salinity resulting from reduced freshwater inflows. For further information see Section 2.2.2.

C. That the Detailed Investigative Phase considers:
   - the vulnerability of Australian Bass breeding to altered estuary salinity resulting from reduced freshwater inflows;
   - the vulnerability of Sydney rock oysters to altered estuary salinity resulting from reduced freshwater inflows;
   - the vulnerability of other fish species of interest or significance identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows; and
   - the vulnerability of Sydney rock oysters to altered estuary water quality resulting from reduced freshwater inflows.

   For further information see Section 2.2.3.

D. That the Detailed Investigative Phase:
   - considers the vulnerability of other river dependant fauna identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows; and
   - should not consider the vulnerability of the water rat, as it is an opportunistic species with a high degree of adaptability to varied conditions in a wide range of habitats.

   For further information see Section 2.2.4.

E. That the Detailed Investigative Phase considers the vulnerability of estuary macroinvertebrate species to altered estuary salinity resulting from reduced freshwater inflows, using information from the Flora and Fauna Review investigation and the studies conducted by The Ecology Lab. For further information see Section 2.2.5.

F. That the Detailed Investigative Phase considers the vulnerability of aquatic and riparian vegetation of interest or significance identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows. For further information see Section 2.2.6.

G. That the Detailed Investigative Phase includes investigation to determine:
   - which of the ephemeral freshwater ponds on the floodplain are dependent on flood flows directly from the river; and
   - the vulnerability of any identified wetlands to altered estuary conditions resulting from reduced freshwater inflows.

   For further information see Section 2.2.7.

H. That the Detailed Investigative Phase considers the vulnerability of China-Australia Migratory Bird Agreement (CAMBA) and Japan-Australia Migratory Bird Agreement (JAMBA) species identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows. For further information see Section 2.2.8.

I. That the Detailed Investigative Phase considers the vulnerability of threatened riparian and floodplain species and ecological communities identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows. For further information see Section 2.2.9.

J. That the Detailed Investigative Phase considers the flushing flows needed to flush all saline water from the deep pools in the upper estuary. For further information see Section 2.2.10.

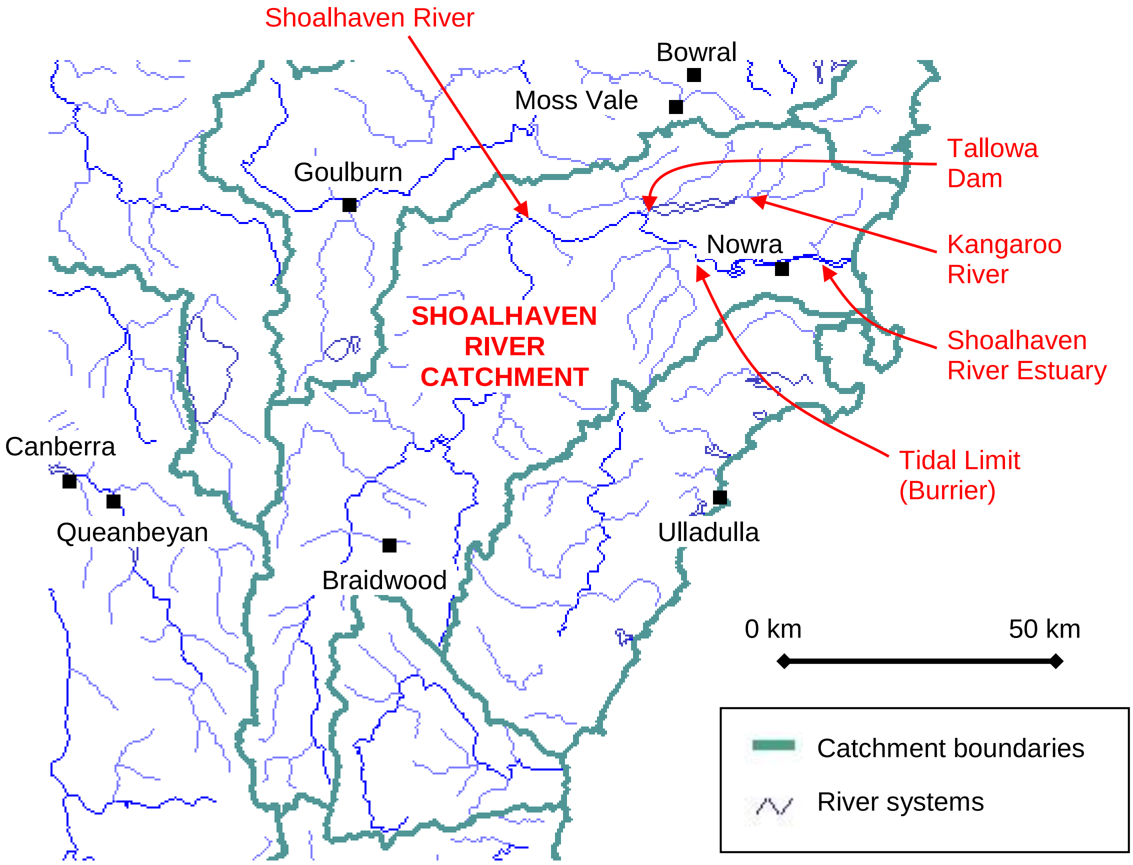
1. Introduction

1.1 Purpose of this paper

1.1.1 Development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam

The Shoalhaven Scheme is located inland from Nowra on the NSW South Coast, and was built in the 1970's for the dual purpose of water supply and hydroelectric power generation (SCA 2002). The Scheme includes Tallowa Dam, which is located immediately downstream of the junction of the Kangaroo and Shoalhaven Rivers (Figure 1). Water from Tallowa Dam has been used to augment the drinking water supply to Sydney during drought, and also to supply local communities.

Figure 1. Shoalhaven River catchment.
(Source: Adapted from New South Wales Natural Resource Atlas).



In October 2004 the NSW Government released the Metropolitan Water Plan (DIPNR 2004). 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 (NSW Government 2006a).

For the Shoalhaven, the Government has announced that it will not proceed with raising Tallowa Dam wall. However, the Sydney Catchment Authority 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 2006. Further information on the development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam can be found in the following DNR reports:

1. *Determining and managing environmental flows for the Shoalhaven River, Report 1 - Environmental Flows Knowledge Review* (available in August 2006) (Boyes 2006a).
2. *Determining and managing environmental flows for the Shoalhaven River, Report 2 - Environmental Flows Investigations* (available in August 2006) (Boyes 2006b).
3. *Determining and managing environmental flows for the Shoalhaven River, Report 3 - Environmental Flows Options Analysis* (available later in 2006).

It is recommended that this Discussion Paper is read in conjunction with these DNR reports.

1.1.2 Estuary Modelling and Assessment investigation

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

1. *Knowledge review* - Compilation and analysis of previous knowledge to provide an understanding of the Shoalhaven River downstream of Tallowa Dam, identify the known effects of the dam and its operation 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.

The knowledge review step was completed in 2005. From the conclusions of the knowledge review and the advice of specialists in NSW Government agencies, the following investigations were initiated:

1. Hydrologic (Flow) Analysis and Modelling.

2. Physical and Ecological Investigations:
    - Water Quality Assessment;
    - Thermal Regime Assessment;
    - Flora and Fauna Review;
    - Aquatic Invertebrates Study;
    - Physical Habitat Modelling;
    - Fish Passage Study; and
    - Estuary Modelling and Assessment.
3. Social, Economic and Cultural Heritage Assessments.

This paper discusses the Estuary Modelling and Assessment investigation.

1.1.3 Flora and Fauna Review investigation

One of the other investigations being carried out as part of the process for the development of a new environmental flow regime for the Shoalhaven River downstream of Tallowa Dam is the Flora and Fauna Review investigation.

The aim of the Flora and Fauna Review is to better understand the relationships between river flow and the flora and fauna species and communities that occur in, or rely upon, the Shoalhaven River downstream of Tallowa Dam, including the Shoalhaven estuary and riparian (riverbank) habitats. The key objectives of the Flora and Fauna Review are to identify:

- the flora and fauna species and vegetation communities documented for the area encompassing the Shoalhaven River downstream of Tallowa Dam;
- the flora and fauna species and vegetation communities in that area that have conservation status under either State or Commonwealth legislation; and
- those threatened species and communities that have specific or known river flow requirements for their successful recruitment, growth and functioning.

The Flora and Fauna Review investigation is closely associated with the Estuary Modelling and Assessment investigation. A report on the Flora and Fauna Review investigation will be available later in 2006.

1.2 The Shoalhaven River estuary and its management

An estuary is the lower reaches of a creek, river or lake where freshwater meets saltwater, where the randomly varying discharges from upstream catchment areas meet the cyclic tidal ebb and flood, and where the aquatic flora and fauna of freshwater regimes meet their marine counterparts. In hydraulic terms, the upstream boundary of an estuary is the limit of tidal influence. The downstream boundary is not always obvious, but it corresponds to the seaward limit of the entrance bar in most situations in NSW. (DNR undated).

The NSW Estuary Management Program was established in 1992 to restore and protect estuaries along the NSW coast. DNR administers the Estuary Management Program, but program decisions and activities are carried out through local government. Local councils establish Estuary Management Committees to oversee the development and implementation of Estuary Management Plans that address the range of environmental matters facing a specific estuary, as well as the economic and social values of the estuary. (DNR 2004).

An Estuary Management Plan is currently being prepared for the Shoalhaven River estuary (Umwelt in prep.). Shoalhaven City Council commenced the process of preparing an Estuary Management Plan by preparing an Estuary Data Compilation Study in 1999. An updated Shoalhaven River Estuary Data Compilation Study has since been prepared (Umwelt 2005), reflecting the significant changes to the natural resource management framework in NSW since 1999, the number of additional technical investigations that have been completed for various sections of the estuary, and new demands on catchment and estuary assets.

The Shoalhaven River Estuary Data Compilation Study summarises and reviews the information available to assist decision makers to plan for sustainable management of the Shoalhaven River estuary, and identifies critical factors influencing sustainable health of the estuary (Umwelt 2005). The Study has informed the preparation of, and defined the study area for, this paper. The location and boundaries of the Shoalhaven estuary study area as defined by the Shoalhaven River Estuary Data Compilation Study are shown in Figure 1, and were determined in accordance with:

- the requirements of the NSW Estuary Management Manual;
- Healthy Rivers Commission (HRC) comments about the integration of floodplain and estuary management; and
- deliberations of the Shoalhaven River Natural Resource and Floodplain Management Committee.

1.3 A methodology for investigating environmental flows for the Shoalhaven River estuary

In 1994, the Council of Australian Governments (COAG) agreed to an innovative Water Reform Framework for Australia. Major reforms were needed to ensure that the trend towards degradation was reversed and that Australia's water resources were used sustainably in the long term. The National River Health Program supports the environmental components of the Water Reform Framework. A major component of the National River Health Program is the Environmental Flows Initiative, which is determining how to best identify the environmental flow needs of rivers and to implement environmental water allocations and reduce future environmental risks. It is also addressing some of the knowledge gaps which exist in environmental flow management. (DEH 2005a).

National reports published under the Environmental Flows Initiative provide an overview of the environmental water requirements of three major ecosystem types, an analysis of threats to these systems and methods for determining water allocations (DEH 2005b). The three National reports are:

- Technical Report No. 1 (2001) - Environmental Water Requirements to Maintain Wetlands of National and International Importance;
- Technical Report No. 2 (2001) - Environmental Water Requirements of Groundwater Dependent Ecosystems; and
- Technical Report No. 3 (2002) - Environmental Water Requirements to Maintain Estuarine Processes.

Technical Report Number 3 ‘Environmental Water Requirements to Maintain Estuarine Processes’ (Peirson *et al.* 2002) identifies that in spite of the significance of estuaries within catchment systems, studies of environmental flows to estuaries are relatively scarce. The Report authors found that:

- it appears that only the United Kingdom has endeavoured to address environmental flows to estuaries in a national and systematic fashion;

- substantial investigations have also been undertaken in South Africa and the United States;
- only two substantial Australian investigations to determine appropriate environmental flows to estuaries could be identified, one on the Derwent River in Tasmania and the other on the Richmond River in NSW; and
- the Richmond River study appears to be the first in Australia to link catchment hydrology with an estuarine salt model to an ecological risk analysis.

The investigations by Peirson *et al.* (2002) have drawn on these overseas and Australian studies to develop a methodology for assessing the risk to the estuarine ecosystems associated with reduced freshwater inflows that is suited to estuaries within Australia (Table 1). The methodology is composed of two phases: a Preliminary Evaluation Phase and a Detailed Investigative Phase. The Preliminary Evaluation Phase aims to yield a classification of estuaries by significance and risk as well as the scope of more detailed investigative programs. The purpose of the Detailed Investigative Phase is to determine an appropriate level of environmental freshwater flow for any given estuary.

Table 1. Methodology for assessing the risk to the estuarine ecosystems associated with reduced freshwater inflows.
(Source: Peirson *et al.* 2002).

Preliminary Evaluation Phase	
PEP Step 1:	*Define the environmental flow issue to be investigated*
PEP Step 2:	*Assess the value of the estuary*
PEP Step 3:	*Assess changes to inflow*
PEP Step 4:	*Assess the vulnerability of the estuary*
Detailed Investigative Phase	
DIP Step 1:	*Examine the likely impact of current water use on transport, mixing, water quality and geomorphology using catchment runoff and estuarine flow models*
DIP Step 2:	*Define environmental flow scenarios for the estuary*
DIP Step 3:	*Use the established models to assess the impact of proposed scenarios*
DIP Step 4:	*Assess the risk to estuarine biota*
DIP Step 5:	*Specification of environmental flow regime*
DIP Step 6:	*Adaptive management*

The methodology uses the following checklist of major ecological processes, by which reduced estuary freshwater inflows may cause impacts on estuarine ecosystems and the adjacent marine environment (Table 2). To prepare the checklist, Peirson *et al.* (2002) adapted and expanded a checklist prepared from literature review by Bishop (1999) to assess the potential impacts of large-scale water diversions on the fisheries of the Clarence River estuary in NSW.

Figure 2. Shoalhaven River estuary study area.
(Source: Umwelt 2005, Figure 1.3, p. 1.13).

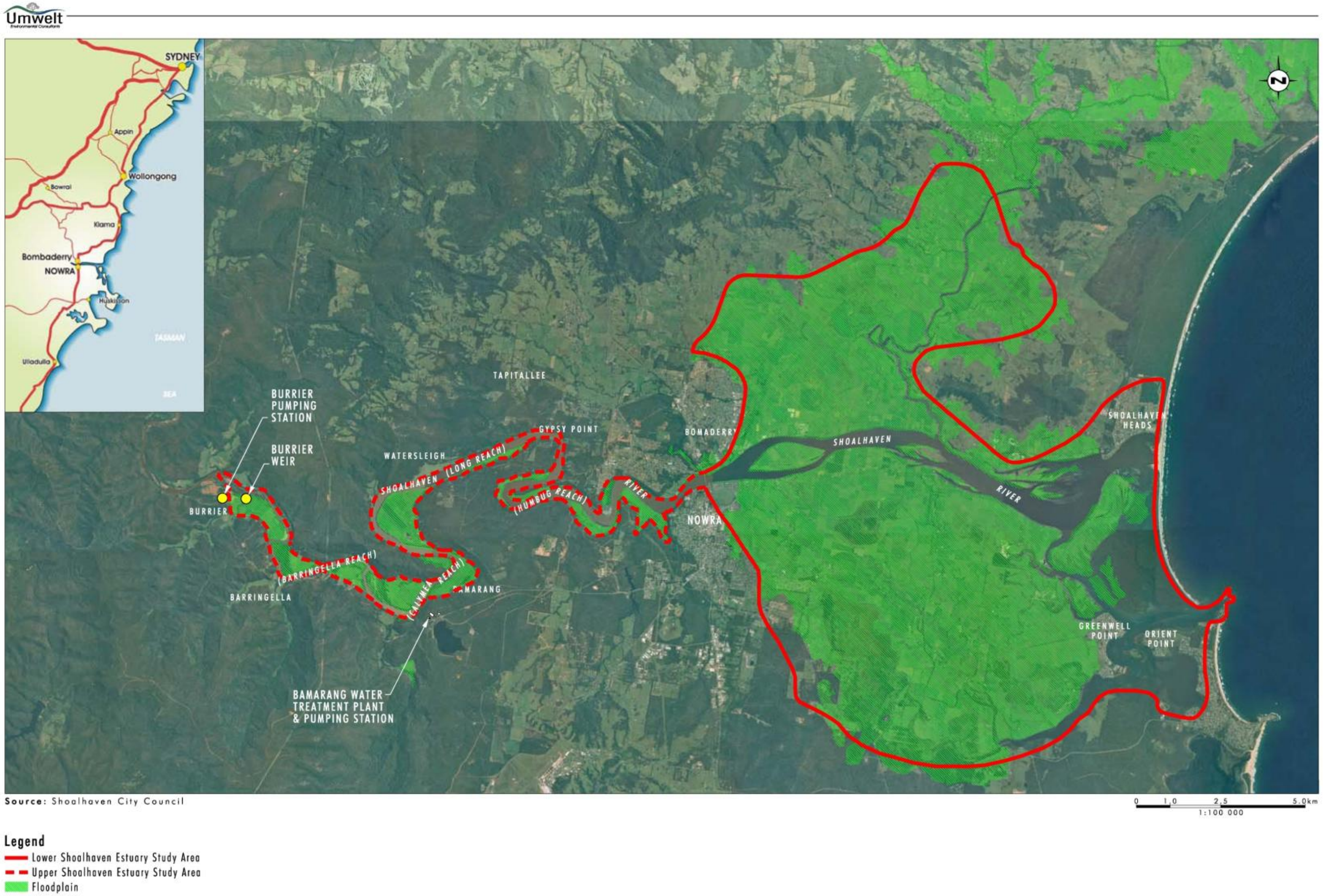


Table 2. Checklist of major ecological processes by which reduced estuary inflows may cause impacts on estuarine ecosystems and adjacent marine environment.
(Source: Peirson *et al.* 2002).

Low magnitude inflows (Low-)	
Low-1:	*Increased hostile water-quality conditions at depth*
Low-2:	*Extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive fauna*
Low-3:	*Extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive flora*
Low-4:	*Extended durations of elevated salinity in the lower estuary allowing the invasion of marine biota*
Low-5:	*Extended durations when flow-induced currents cannot suspend eggs or larvae*
Low-6:	*Extended durations when flow-induced currents cannot transport eggs or larvae*
Low-7:	*Aggravation of pollution problems*
Low-8:	*Reduced longitudinal connectivity with upstream river systems*
Middle and high magnitude inflows (M/H-)	
M/H-1:	*Diminished frequency that the estuary bed is flushed of fine sediments and organic material (physical-habitat quality reduction)*
M/H-2:	*Diminished frequency that deep sections of the estuary are flushed of organic material (subsequent water quality reduction)*
M/H-3:	*Reduced channel-maintenance processes*
M/H-4:	*Reduced inputs of nutrients and organic material*
M/H-5:	*Reduced lateral connectivity and reduced maintenance of ecological processes in waterbodies adjacent to the estuary*
Across all inflow magnitudes (All-)	
All-1:	*Altered variability in salinity structure*
All-2:	*Dissipated salinity/chemical gradients used for animal navigation and transport*
All-3:	*Decreases in the availability of critical physical-habitat features, particularly the component associated with higher water-velocities*

The Preliminary Evaluation Phase of the Peirson *et al.* (2002) methodology has been carried out for the Shoalhaven River estuary, and the results are documented in this paper. From these results, recommendations for the scope of the Detailed Investigative Phase for the Shoalhaven River estuary are made.

2. Application of methodology

2.1 Preliminary Evaluation Phase

2.1.1 PEP Step 1: Define the environmental flow issue to be investigated

The Peirson *et al.* (2002) methodology advises that there are at least two ways that environmental flows questions can be posed:

1. What are the implications of proposed reduced flows on the environment? This is a question concerning proposed *future development* or *assessment of scenarios*.
2. What is the required effective environmental flow regime that is required in this estuary? This is a question concerning *estuary rehabilitation or protection* or *determination of critical thresholds*.

The answers to these questions determine the emphasis and scope of the entire investigation. When proposed future developments are in question, investigators can design a far more focussed study by identifying the likely impacts of the development on the ecosystem and determine those facets most susceptible to the impacts. Questions regarding estuary rehabilitation, protection or critical salinity thresholds are far more wide ranging and, as a consequence, will need much more detailed investigation.

The environmental flow issue to be investigated in this case relates to the proposed increased transfers of water from Tallowa Dam to other SCA storages, and the associated implications of reduced flows on the environment. Under current arrangements only 15 GL/year on average, or approximately 2.5% of mean annual natural flow, is transferred from Tallowa Dam (SMEC 2002 p. 8). The NSW Government proposes that up to 30 GL/year of additional water could be transferred (NSW Government 2006b p. 11). Because the environmental flow issue to be investigated relates to proposed future development, a focussed study can be carried out that identifies the likely impacts of reduced inflows on the values of the Shoalhaven River estuary and determines those facets most susceptible to the impacts of reduced flows.

2.1.2 PEP Step 2: Assess the value of the estuary

The methodology alerts that high-value estuaries, as opposed to low-value estuaries, warrant more protection from inflow-reduction processes, and recommends that the value of the estuary is considered from the following perspectives:

1. Conservation:
   - high, if pristine;
   - high, if threatened or endangered species or communities occur;
   - high, if listed wetlands occur;
   - high, if rare habitats occur; and
   - high, if a diverse range of habitats occur.
2. Commercial:
   - high, if productive commercial fisheries occur, and
   - high, if scenic features attract tourists.
3. Recreational:
   - high, if productive and popular recreational fisheries occur.
4. Scenic:
   - high, if scenic values are high and publicly appreciated.

5. Links:
    - high, if associated with regional, national or international ecological links, treaties or agreements regarding fauna.

Table 4 shows the values perspectives for which the Shoalhaven River estuary is assessed as a high-value estuary. The primary reference for the value assessment has been the Shoalhaven River Estuary Data Compilation Study (Umwelt 2005). Locations in Table 4 are shown in Figure 3.

2.1.3 PEP Step 3: Assess changes to inflow

The methodology identifies that there are four inflow variables for an estuary, and that these variables and changes to their magnitude due to human activity need to be quantified. The four inflow variables are:
1. Freshwater extractions from the estuary or its catchment.
2. Saltwater exchange at the estuary entrance.
3. Anthropogenic discharges to the estuary or its catchment.
4. Groundwater flowing to the estuary or its catchment.

These four inflow variables for the Shoalhaven River estuary and changes to their magnitude due to human activity are listed in Table 5. Locations in Table 5 are shown in Figure 3. It is recommended that Table 5 is read in conjunction with Chapter 2 of the DNR Report *Determining and managing environmental flows for the Shoalhaven River, Report 1 - Environmental Flows Knowledge Review* (see Section 1.1.1).

From Table 5, the following conclusions can be drawn:
1. Water extractions to date have not significantly affected medium or high flows to the Shoalhaven River estuary.
2. Low flows to the Shoalhaven River estuary have been negatively affected by transfers from Tallowa Dam to Sydney and extraction by Shoalhaven City Council.
3. Low flows have also potentially been negatively affected by a range of other extractions from the estuary and its catchment, but these extractions are small in comparison to the transfers from Tallowa Dam to Sydney and extraction by Shoalhaven City Council.
4. Anthropogenic discharges and groundwater flows are not significant sources of inflow to the Shoalhaven River estuary.

On the basis of the assessment of inflow shown in Table 5, the methodology states that estuarine catchments can be classified according to their level of freshwater usage. Table 3 suggests recommended values for this classification.

Table 3. Classification of estuarine catchments according to freshwater usage. (Source: Peirson *et al.* 2002).

Freshwater usage	Catchment area flowing to storage or major diversion (%)	Water usage as a proportion of stressed river flow (%)
Very high	>10	>85
High	2-10	65-85
Moderate	0.4-2	35-65
Low	<0.4	0-35

80% of the combined Shoalhaven and Kangaroo River catchment area flows to the Tallowa Dam storage (Norman and Turner 1999 p. 11), and from the second column of Table 3 this suggests a ‘very high’ freshwater usage classification.

The “stressed river flow” in the third column of Table 3 is the mean daily flow exceeded for 80% of days in the month of maximum water usage. If the river ceases to flow for more than 20% of the days in the month of maximum water usage, the mean daily flow exceeded for more than 50% of days is used. The thresholds for the proportion of catchment area flowing to storage or diversion were obtained by reviewing selected Australian estuaries that are reputed to have problems associated with environmental flows.

The NSW Stressed Rivers Assessment Report assesses the Overall Stress Classification for the Shoalhaven Estuary as “Unresolved” (DLWC 1998 p. 47). However, the results of a different assessment can instead be used to draw conclusions about water usage as a proportion of stressed river flow. In 2002, the Snowy Mountains Engineering Corporation (SMEC) examined river flows in the Hawkesbury-Nepean, Shoalhaven and Woronora river systems (SMEC 2002 pp. 8-9). When median flows in the Shoalhaven River 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 median flows of the Shoalhaven River are reduced by only negligible amounts, the impact during low flow periods is severe. This supports a ‘very high’ freshwater usage classification during low flow periods.

As shown in Table 5, only low-magnitude inflows are currently being affected by water extractions, but this could change if future transfers target middle or high flows. Because of this, the vulnerability of the estuary to reductions in flow across the full flow range needs to be investigated.

Table 4. Values assessment of the Shoalhaven River estuary.

Values perspectives identified by Peirson *et al.* (2002)	**Is the Shoalhaven River estuary assessed as high value?**	**Justification for values assessment**
1. Conservation values		
• High, if pristine	No	• The estuary is not in a pristine, undisturbed condition. Significant human-induced changes have occurred, including the clearing of the floodplain for farming, the undertaking of flood mitigation measures that mean only the largest floods can now connect with the floodplain wetlands temporarily, and the construction of Berrys canal which has substantially altered the lower estuary (Boyes 2006a pp. 32-33). • Additionally, the riparian zone of the lower estuary is badly degraded due to vegetation clearing, trampling by cattle and the presence of exotic species. This degradation has contributed to bank slumping and erosion. Many of the lateral wetlands that were once present in this reach have also been drained. (Coysh *et al.* 2005 p. 41).
• High, if threatened or endangered species or communities occur	Yes	• There are a large number of threatened species and ecological communities in the riparian corridor and on the floodplain of the Shoalhaven River estuary (Umwelt 2005 p. 10.1, NPWS 2005a).
• High, if listed wetlands occur	Yes	• There are significant wetlands located within the estuary floodplain area (Umwelt 2005 pp. 10.6-10.8). The Directory of Important Wetlands in Australia lists 78% of the wetlands in the Shoalhaven catchment as important (Coysh *et al.* 2005 p. 41). • Wetlands of the Shoalhaven estuary provide important bird habitat, with the area classified as one of the three most important waterbird areas in NSW (Coysh *et al.* 2005 p. 41).
• High, if rare habitats occur	Yes	• There are significant habitats in the riparian corridor and on the floodplain of the Shoalhaven River estuary (Umwelt 2005 pp. 10.1-10.9, NPWS 2005a).
• High, if a diverse range of habitats occur	Yes	• The Shoalhaven is a highly diverse area containing many significant ecological features (Umwelt 2005 p. 10.4).

Values perspectives identified by Peirson *et al.* (2002)	Is the Shoalhaven River estuary assessed as high value?	Justification for values assessment
2. Commercial values		
• High, if productive commercial fisheries occur	Yes	• The estuary supports important commercial fisheries (fish and prawns) and high-value commercial oyster leases (Norman and Turner 1999 pp. 63-65). A report on the status of NSW fisheries resources in 2001/2002 did not identify the Shoalhaven estuary as one of the top 10 estuary fisheries in NSW (Kennelly and McVea 2003 p. 88), however it is significant to the Shoalhaven economy (SCC 2001a).
• High, if scenic features attract tourists	Yes	• The lower part of the estuary (the Shoalhaven and Crookhaven Heads areas) is a popular holiday and sightseeing area, linked to coastal recreation and tourism. Fishing, swimming and birdwatching are popular activities in these locations. (Umwelt 2005 p. 13.3).
3. Recreational values		
• High, if productive and popular recreational fisheries occur	Yes	• Recreational fishing is a popular activity in the estuary (Umwelt 2005 pp. 13.3 & 13.4).
4. Scenic values		
• High, if scenic values are high and publicly appreciated	Yes	• The Shoalhaven River is a key scenic feature of the region. The natural environment, and its role in quality of life, is a major attraction of the area. (SCC 2001b). • The estuary is used for many public activities including water skiing, wake boarding, sailing, rowing, river cruises and swimming. The natural bushland areas adjacent to the river are used for camping, picnicking, bushwalking, bird watching and other passive pursuits. (Umwelt 2005 p. 13.3).
5. Links		
• High, if associated with regional, national or international ecological links, treaties or agreements regarding fauna	Yes	• The Shoalhaven estuary has wetlands of national significance (Coysh *et al.* 2005 p. 41, DLWC 2000). • The Shoalhaven estuary supports migratory waterbird species covered by the China-Australia Migratory Bird Agreement (CAMBA) and Japan-Australia Migratory Bird Agreement (JAMBA) (NPWS 2005b, DEH 2005c).

Table 5. Inflow variables for the Shoalhaven River estuary, changes due to human activity, and the magnitude of these changes.

It is recommended that this table is read in conjunction with Chapter 2 of the DNR Report *Determining and managing environmental flows for the Shoalhaven River, Report 1 - Environmental Flows Knowledge Review* (see Section 1.1.1).

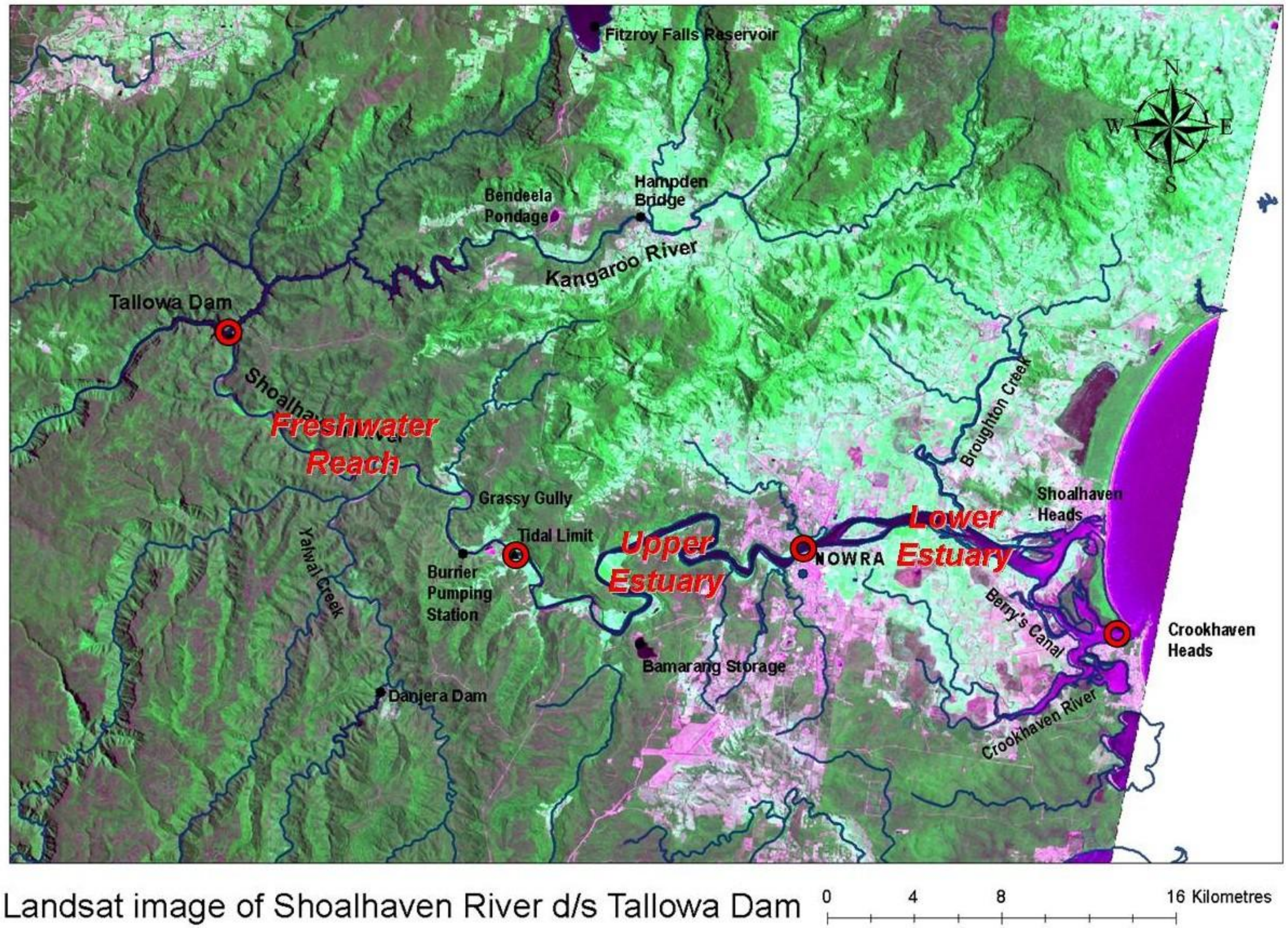
Inflow variables	Changes due to human activity	Magnitude of change (quantitative)	Magnitude of change (qualitative)
1. Freshwater extractions from the estuary or its catchment.	The 48 weirs in the Shoalhaven River catchment (Kingsford *et al.* 2004 p. 29).	Unknown.	The 48 weirs in the Shoalhaven catchment are identified as a major threat to downstream floodplain wetlands (Kingsford *et al.* 2004 p. 29). The location of the weirs within the catchment is not stated, and detailed information on how the weirs affect river flow is not given. Any impact of the weirs would be likely to be greatest in drought (low flow) periods.
	Transfers from Tallowa Dam to Sydney (current and previous).	Under current operating conditions only 15 GL/year on average, or approximately 2% of mean annual natural flow, is transferred (SMEC 2002 p. 8). Transfers have occurred during three periods of drought: Aug 1980 - Nov 1984 approx. 430 GL; Jun 1994 - May 1995 approx. 140 GL; Apr 2003 - Jun 2005 approx. 260 GL (Coysh *et al.* 2005 p. 18). Average annual inflow to Tallowa Dam is 868.1 GL/yr, and average annual release is 846.8 GL/yr (SMEC 2002 Figure 3a).	There is some loss of low flows under current operating conditions. However, apart from the impact on low flows, the current regime closely matches the flow under natural conditions. (Coysh *et al.* 2005 p. 23).
	Transfers from Tallowa Dam to Sydney (future).	The NSW Government proposes that up to 30 GL/year of additional water could be transferred from Tallowa Dam (NSW Government 2006b p. 11).	The proposed increased transfers are likely to target middle flows and the lower end of high flows.

Inflow variables	Changes due to human activity	Magnitude of change (quantitative)	Magnitude of change (qualitative)
	Extraction by Shoalhaven City Council.	Shoalhaven City Council extracts up to 90 ML/day at Burrier, below Tallowa Dam, but is not permitted to divert if inflows are less than 90 ML/day (Coysh *et al.* 2005 p. 18). Shoalhaven City Council diverted approx. 16,000 ML/yr from 2001-2004, which was 3.55% of inflow in 2001/02, 7.32% of inflow in 2002/03 year, and 11.55% of inflow in 2003/04 (Coysh *et al.* 2005 p. 22).	The Shoalhaven City Council extraction compounds the loss of low flows to the estuary under regulated conditions.
	Danjera Dam.	Water is not extracted directly from Danjera Dam, but can be released via Yalwal Creek if required by Shoalhaven Water (Coysh *et al.* 2005 p. 18). Danjera Dam impounds runoff from an area equivalent to approximately 10% of the Yalwal subcatchment (Norman and Turner 1999 p. 13).	Minimal.
	Use of water by Eraring Energy.	Eraring Energy is entitled to interchange up to a maximum of 4,021 ML between Lake Yarrunga (the water storage formed by Tallowa Dam) and Fitzroy Falls Reservoir at any time, and may interchange up to 10,000 ML in conditions of unusually high power demand or the failure of other generating capacity (DLWC 2003 p. 4).	Minimal.
	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 (Boyes 2006a p. 36).	Minimal.
	Extraction of water for domestic purposes and stock watering by landowners with a direct river frontage under the *Water Management Act 2000*	Unknown. Is being addressed by the water sharing plan preparation process for the greater Sydney Metropolitan region (Boyes 2006b p. 53).	Unknown, but likely to be minimal.

Inflow variables	Changes due to human activity	Magnitude of change (quantitative)	Magnitude of change (qualitative)
2. Salt water exchange at the estuary entrance.	The current estuary entrance 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. (Boyes 2006a p. 32).	Unknown.	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 (IEP 2004 p. 54). This would mean that the construction of Berrys Canal would have introduced permanent tidal conditions to the estuary, significantly altering estuarine ecology. 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. 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 (Umwelt 2005 p. 5.7-5.8). 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 p. 2.1).

Inflow variables	Changes due to human activity	Magnitude of change (quantitative)	Magnitude of change (qualitative)
3. Anthropogenic discharges to the estuary or its catchment.	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. (Boyes 2006a p. 37).	Minimal.	Minimal.
4. Groundwater flowing to the estuary or its catchment.	Groundwater is not well understood in the Shoalhaven River catchment. DNR has no monitoring bores in the catchment, and there are few studies in existence. To collect sufficient useful information would require extensive groundwater monitoring and analysis. This is not practical or cost effective, as specialists in NSW Government agencies have advised that groundwater inputs are not likely to be large in the part of the river of interest. (Boyes 2006b p. 53).	Minimal.	Minimal.

Figure 3. Shoalhaven Estuary downstream of Tallowa Dam.
(Source: Adapted from I. Reinfelds, DNR).



Landsat image of Shoalhaven River d/s Tallowa Dam

2.1.4 PEP Step 4: Assess the vulnerability of the estuary

For this step, the methodology advises that an *interaction matrix* should be prepared to highlight the specific vulnerabilities of the given estuary and establish priorities for more detailed investigation. The matrix should have the valued aspects of the estuary (as identified in Table 4) on one axis and the major ecological processes (as shown in the checklist in Table 2) on the other axis.

If a specific aspect is designated as being of high value, and it is vulnerable to a flow reduction process, then the component in conjunction with the specific process warrants particular consideration. In practice, there may be significant gaps in the available information about some estuaries. If this is the case, these gaps will be revealed during this phase of the investigations and the potential values and vulnerability of these estuaries can be noted as requiring appropriate levels of investigation.

Interaction matrices for the Shoalhaven River estuary are shown in Table 8 and Table 9, with the vulnerability assessment referring to discussion of, and recommendations for, the scope of the Detailed Investigative Phase of the methodology. The discussion and recommendations are found in Section 2.2, which immediately follows Table 9.

The preparation of Table 8 and Table 9 draws primarily on the findings of the Cooperative Research Centre (CRC) for Freshwater Ecology study prepared for the Scientific Advisory Panel (Coysh *et al.* 2005) and on the Shoalhaven River Estuary Data Compilation Study prepared for Shoalhaven City Council (Umwelt 2005).

The checklist of major ecological processes used in Table 8 and Table 9 is further explained in Table 7. The checklist uses the terms ‘upper-middle estuary’ and ‘lower estuary’, and the estuary reaches/areas to which these terms correspond are shown in Table 6.

Table 6. Estuary reaches/areas corresponding to the terms ‘upper-middle estuary’ and ‘lower estuary’ in the checklist of major ecological processes shown in Table 7.

Reaches shown in Figure 3	Terms used in the checklist of major ecological processes shown in Table 7	Terms used by Hawkesbury Nepean River Management Forum Independent Expert Panel (IEP 2004)	Terms used in Shoalhaven Estuary Data Compilation Study (Umwelt 2005) and as shown in Figure 1
Upper estuary	Upper-middle estuary	Reach 2.1	Upper Shoalhaven Estuary Study Area
Lower estuary	Lower estuary	Reach 2.2	Lower Shoalhaven Estuary Study Area

Table 7. Explanation of ecological processes by which reduced estuary freshwater inflows may cause impacts on estuarine ecosystems and adjacent marine environment. (Source: Peirson *et al.* 2002).

Low-magnitude inflows (Low-):
Low-1: Increased hostile water-quality conditions at depth Reduced inflows, and concomitant reduced vertical mixing (turbulence), resulting in hostile water-quality conditions (e.g. low Dissolved Oxygen (DO) at depth) in deep sections within the upper-middle estuary where water retention times are protracted; higher salinity at depth would aggravate problems with DO; demersal eggs and large-size taxa are at most risk because they are found in deeper sections where water quality is likely to be most hostile.
Low-2: Extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive fauna Reduced inflows resulting in extended durations of elevated salinity in the upper-middle estuary; fauna with low salinity tolerance (eggs, larvae, juveniles or adults) could be adversely affected through physiological stress and/or by competition and predation from colonising large fauna normally found in the lower estuary; increased parasitism may also be involved; avoidance response to salinity may cause occupation of suboptimal habitat and/or overcrowding; the low-salinity region of an estuary is indicated as acting as an important nursery ground for juvenile fish and invertebrates.
Low-3: Extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive flora Reduced inflows resulting in extended durations of elevated salinity in the upper-middle estuary; instream and/or riparian plants with low salinity tolerance will be adversely affected through physiological stress; a considerable range of subsequent impacts could result: loss of shelter and foraging areas (riparian & instream plants) for fauna, reduced water quality as plants have diminished capacity to trap nutrients and sediments (riparian & instream), reduced bank stability if riparian plants die and subsequent water-quality deterioration if collapsed bank materials release nutrients to the water.
Low-4: Extended durations of elevated salinity in the lower estuary allowing the invasion of marine biota Reduced inflows resulting in extended durations of elevated salinity in the lower estuary; marine biota thus able to colonise the lower portion of the estuary; sensitive biota either displaced through competition or predated upon, and may be additionally disadvantaged by high-salinity induced physiological stress.
Low-5: Extended durations when flow-induced currents cannot suspend eggs or larvae Reduced inflows resulting in extended durations when flow-induced currents cannot suspend eggs or larvae in the upper-middle estuary; eggs or larvae settle to the bottom and mortality results.
Low-6: Extended durations when flow-induced currents cannot transport eggs or larvae Reduced inflows resulting in extended durations when flow-induced currents cannot transport eggs or larvae in the upper-middle estuary to favourable habitats for later life-history stages (inhibition of advection); growth/recruitment opportunities are lost.

Low-7: Aggravation of pollution problems Reduced inflows aggravating pollution problems in the upper-middle estuary originating from either agricultural, industrial or urban pollution sources; may include consequent biological ‘pollution’ (e.g. algal blooms, etc); lowered dilution of pollutants and/or stratification-induced deoxygenation causing the releases of toxicants from estuary-bed sediments; higher salinity at depth would aggravate problems with DO; consequent lowered abundance of fish, shellfish and crustacea, and contamination of tissues; nutrients may also be released from sediments causing algal problems for example.
Low-8: Reduced longitudinal connectivity with upstream river systems Decreased inflows can sever, or halt the establishment of, connectivity between the estuary and upstream river systems; this can have severe impacts on fauna with diadromous lifecycles (e.g. mobile fauna such as fish and crustaceans).
Middle- and high-magnitude inflows (M/H-):
M/H-1: Diminished frequency that the estuary bed is flushed fine sediments and organic material (physical-habitat quality reduction) Reduced inflows greatly altering the frequency that the bed of the upper-middle estuary is flushed of fine sediments and organic material (i.e. high flows causing substrate turnover); this is significant as many fauna lay their eggs on or within hard substrates - the presence of sediment/organic matter will result in lowered reproductive success as suitable egg deposition/attachment sites will become limited.
M/H-2: Diminished frequency that deep sections of the estuary are flushed of organic material (subsequent water quality reduction) Reduced freshwater inflows greatly altering the frequency that organic material deposited on the bed of deep sections in the upper-middle estuary is flushed out; this is significant as a high organic load can result in hostile water-quality conditions (for example, low DO); again demersal eggs and poorly mobile taxa are at most risk.
M/H-3: Reduced channel-maintenance processes Reduced inflows greatly reducing channel-maintenance processes (mediated by flushing flows) in the upper-middle estuary with a result that major habitat contraction occurs in the long-term; deep sections of the estuary are most vulnerable as very large flows are required to remove infilling material; again demersal eggs and large-sized taxa are at most risk; could be relevant to the lower estuary in respect to the closing of the estuary mouth through the deposition of transported marine sands; a range of impacts on migrating fauna may result from the reduced estuary-marine connectivity; water quality impacts could occur if tidal exchange flushing is substantially reduced.
M/H-4: Reduced inputs of nutrients and organic material Decreased inflows subsequently reducing the input of natural river-borne nutrients and organic material; reduced primary production followed by reduced zooplankton abundance along the length of the estuary and into adjacent coastal areas; fish and crustacean abundance diminishes in response to decreased food supply and sheltering areas (instream plants).
M/H-5: Reduced lateral connectivity and reduced maintenance of ecological processes in waterbodies adjacent to the estuary Decreased inflows can sever, or halt the establishment of, connectivity between the estuary and adjacent waterbodies (floodplain billabongs, wetlands, etc) for mobile fauna; the loss of connecting flows may also result in ecological processes in the waterbodies not being activated or maintained.

Across all inflow magnitudes (All-):
All-1: Altered variability in salinity structure Altered variability of inflows to the estuary, and the consequent change in patterns of variation in the salinity structure of the estuary, is likely to disrupt life cycles as suitably-timed breeding and/or migration cues for fish and crustaceans are masked; can also have relevance to plants; growth/recruitment opportunities are lost because of a lack of synchronization with the temperature regime.
All-2: Dissipated salinity/chemical gradients used for animal navigation and transport Reduced inflows which subsequently dissipate salinity & other chemical gradients out from the mouth of the estuary, and/or along the estuary; this is significant as there is evidence that some juvenile estuarine fish & invertebrates species use such gradients to navigate there way into and along estuaries. Salinity-gradient upstream transport mechanisms could also be inhibited.
All-3: Decreases in the availability of critical physical-habitat features, particularly the component associated with higher water-velocities Reduced inflows lower water velocities thereby altering an important physical habitat component, particularly in the upper estuary where tide-induced water currents are less prevalent. Biota favouring higher velocity areas are disadvantaged; generally native biota are disadvantaged more than alien biota.

Table 8. Interaction matrix - vulnerability of the ecological values of the Shoalhaven estuary to the range of potential inflow-reduction processes.

The vulnerability assessment in this table refers to discussion and recommendations for the scope of the Detailed Investigative Phase of the methodology. The discussion and recommendations are found in Section 2.2, which immediately follows Table 8 and Table 9.

Table key: Red text = Potential or possible vulnerability, green text = low vulnerability, blue text = unknown vulnerability, black text = not relevant.

Inflow-reduction processes	**Ecological values**									
	Threatened fish species (Australian Grayling)	**Other fish species**	**Platypus**	**Water rat, turtles, frogs**	**Macro-inverte-brates**	**Aquatic vegetation**	**Riparian vegetation**	**Floodplain wetlands**	**JAMBA/ CAMBA Birds**	**Threatened riparian & floodplain species**
Low-1: increased hostile water-quality conditions at depth [in upper-middle estuary]	Unknown Refer Section 2.2.2	Potentially vulnerable Refer Sections 2.2.3 & 2.2.10	Unknown, but probably low vulnerability Refer Section 2.2.4	Unknown, but probably low vulnerability Refer Section 2.2.4	Unknown Refer Section 2.2.5	Unknown Refer Section 2.2.6	Not relevant	Not relevant	Not relevant	Not relevant
Low-2: extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive fauna	Potentially vulnerable Refer Sections 2.2.1, 2.2.2 & 2.2.10	Potentially vulnerable Refer Sections 2.2.1, 2.2.3 & 2.2.10	Unknown Refer Sections 2.2.1 & 2.2.4	Potentially vulnerable Refer Sections 2.2.1 & 2.2.4	Unknown Refer Sections 2.2.1 & 2.2.5	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant
Low-3: extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive flora	Habitat potentially vulnerable Refer Sections 2.2.1, 2.2.2 & 2.2.10	Habitat potentially vulnerable Refer Sections 2.2.1 & 2.2.10	Unknown, but probably low vulnerability Refer Sections 2.2.1 & 2.2.4	Unknown, but probably low vulnerability Refer Sections 2.2.1 & 2.2.4	Unknown Refer Sections 2.2.1 & 2.2.5	Unknown Refer Sections 2.2.1 & 2.2.6	Unknown Refer Sections 2.2.1 & 2.2.6	Not relevant	Not relevant	Not relevant

Table key: Red text = Potential or possible vulnerability, green text = low vulnerability, blue text = unknown vulnerability, black text = not relevant.										
Inflow-reduction processes	**Ecological values**									
	Threatened fish species (Australian Grayling)	**Other fish species**	**Platypus**	**Water rat, turtles, frogs**	**Macro-inverte-brates**	**Aquatic vegetation**	**Riparian vegetation**	**Floodplain wetlands**	**JAMBA/ CAMBA Birds**	**Threatened riparian & floodplain species**
Low-4: extended durations of elevated salinity in the lower estuary allowing the invasion of marine biota	Low vulnerability Refer Sections 2.2.1 & 2.2.2	Oysters potentially vulnerable, other species low vulnerability Refer Sections 2.2.1 & 2.2.3	Not relevant	Unknown, but probably low vulnerability Refer Sections 2.2.1 & 2.2.4	Unknown Refer Sections 2.2.1 & 2.2.5	Unknown, but probably low vulnerability Refer Sections 2.2.1 & 2.2.6	Low vulnerability Refer Section 2.2.1	Low vulnerability Refer Sections 2.2.1 & 2.2.7	Low vulnerability Refer Sections 2.2.1 & 2.2.8	Low vulnerability Refer Sections 2.2.1 & 2.2.9
Low-5: extended durations when flow-induced currents cannot suspend eggs or larvae [in upper-middle estuary]	Potentially vulnerable Refer Section 2.2.2	Unknown Refer Section 2.2.3	Not relevant	Not relevant for water rat & turtles; unknown for frogs Refer Section 2.2.4	Unknown Refer Section 2.2.5	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant
Low-6: extended durations when flow-induced currents cannot transport eggs or larvae [in upper-middle estuary]	Potentially vulnerable Refer Section 2.2.2	Unknown Refer Section 2.2.3	Not relevant	Not relevant for water rat & turtles; unknown for frogs Refer Section 2.2.4	Unknown Refer Section 2.2.5	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant

Table key: Red text = Potential or possible vulnerability, green text = low vulnerability, blue text = unknown vulnerability, black text = not relevant.

Inflow-reduction processes	Ecological values									
	Threatened fish species (Australian Grayling)	**Other fish species**	**Platypus**	**Water rat, turtles, frogs**	**Macro-inverte-brates**	**Aquatic vegetation**	**Riparian vegetation**	**Floodplain wetlands**	**JAMBA/ CAMBA Birds**	**Threatened riparian & floodplain species**
Low-7: aggravation of pollution problems [in upper-middle estuary]	Low vulnerability due to existing low pollution levels	Oysters potentially vulnerable, other species low vulnerability due to existing low pollution levels Refer Section 2.2.3	Low vulnerability due to existing low pollution levels	Low vulnerability due to existing low pollution levels	Low vulnerability due to existing low pollution levels	Low vulnerability due to existing low pollution levels	Low vulnerability due to existing low pollution levels	Not relevant	Not relevant	Low vulnerability due to existing low pollution levels
Low-8: reduced longitudinal connectivity with upstream river systems	Potentially vulnerable Refer Section 2.2.2	Potentially vulnerable Refer Section 2.2.3	Potentially vulnerable Refer Section 2.2.4	Unknown, but probably low vulnerability Refer Section 2.2.4	Unknown Refer Section 2.2.5	Unknown Refer Section 2.2.6	Potentially vulnerable Refer Section 2.2.6	Potentially vulnerable Refer Section 2.2.7	Unknown Refer Section 2.2.8	Unknown Refer Section 2.2.9
Medium/High-1: diminished frequency that the estuary bed is flushed of fine sediments and organic material (physical-habitat quality reduction)	Unknown Refer Section 2.2.2	Unknown Refer Section 2.2.3	Potentially vulnerable Refer Section 2.2.4	Unknown, but probably low vulnerability Refer Section 2.2.4	Unknown Refer Section 2.2.5	Unknown Refer Section 2.2.6	Potentially vulnerable Refer Section 2.2.6	Low vulnerability Refer Section 2.2.7	Low vulnerability Refer Section 2.2.8	Low vulnerability Refer Section 2.2.9

Table key: Red text = Potential or possible vulnerability, green text = low vulnerability, blue text = unknown vulnerability, black text = not relevant.										
Inflow-reduction processes	**Ecological values**									
	Threatened fish species (Australian Grayling)	**Other fish species**	**Platypus**	**Water rat, turtles, frogs**	**Macro-inverte-brates**	**Aquatic vegetation**	**Riparian vegetation**	**Floodplain wetlands**	**JAMBA/ CAMBA Birds**	**Threatened riparian & floodplain species**
Medium/High-2: diminished frequency that deep sections of the estuary are flushed of organic material (subsequent water quality reduction)	Unknown Refer Section 2.2.2	Unknown Refer Section 2.2.3	Potentially vulnerable Refer Section 2.2.4	Unknown, but probably low vulnerability Refer Section 2.2.4	Unknown Refer Section 2.2.5	Unknown Refer Section 2.2.6	Low vulnerability Refer Section 2.2.6	Low vulnerability Refer Section 2.2.7	Low vulnerability Refer Section 2.2.8	Low vulnerability Refer Section 2.2.9
Medium/High-3: reduced channel-maintenance processes	Potentially vulnerable Refer Section 2.2.2	Potentially vulnerable Refer Section 2.2.3	Potentially vulnerable Refer Section 2.2.4	Unknown, but probably low vulnerability Refer Section 2.2.4	Unknown Refer Section 2.2.5	Unknown Refer Section 2.2.6	Potentially vulnerable Refer Section 2.2.6	Potentially vulnerable Refer Section 2.2.7	Unknown Refer Section 2.2.8	Unknown Refer Section 2.2.9
Medium/High-4: reduced inputs of nutrients and organic material	Unknown Refer Section 2.2.2	Unknown Refer Section 2.2.3	Unknown Refer Section 2.2.4	Unknown, but probably low vulnerability Refer Section 2.2.4	Unknown Refer Section 2.2.5	Unknown Refer Section 2.2.6	Unknown Refer Section 2.2.6	Potentially vulnerable Refer Section 2.2.7	Unknown Refer Section 2.2.8	Unknown Refer Section 2.2.9
All-1: altered variability in salinity structure	Unknown Refer Sections 2.2.1 & 2.2.2	Unknown Refer Sections 2.2.1 & 2.2.3	Unknown Refer Sections 2.2.1 & 2.2.4	Unknown, but probably low vulnerability Refer Section 2.2.1	Unknown Refer Sections 2.2.1 & 2.2.5	Unknown Refer Sections 2.2.1 & 2.2.6	Unknown Refer Sections 2.2.1 & 2.2.6	Low vulnerability Refer Sections 2.2.1 & 2.2.7	Unknown Refer Sections 2.2.1 & 2.2.8	Unknown Refer Sections 2.2.1 & 2.2.9

Table key: Red text = Potential or possible vulnerability, green text = low vulnerability, blue text = unknown vulnerability, black text = not relevant.										
Inflow-reduction processes	**Ecological values**									
	Threatened fish species (Australian Grayling)	**Other fish species**	**Platypus**	**Water rat, turtles, frogs**	**Macro-inverte-brates**	**Aquatic vegetation**	**Riparian vegetation**	**Floodplain wetlands**	**JAMBA/ CAMBA Birds**	**Threatened riparian & floodplain species**
All-2: dissipated salinity/chemical gradients used for animal navigation and transport	Potentially vulnerable Refer Sections 2.2.1 & 2.2.2	Potentially vulnerable Refer Sections 2.2.1 & 2.2.3	Unknown Refer Sections 2.2.1 & 2.2.4	Unknown, but probably low vulnerability Refer Sections 2.2.4	Unknown Refer Section 2.2.5	Not relevant	Not relevant	Not relevant	Unknown Refer Section 2.2.8	Unknown Refer Section 2.2.9
All-3: decreases in the availability of critical physical-habitat features, particularly the component associated with higher water-velocities	Unknown Refer Section 2.2.2	Potentially vulnerable Refer Section 2.2.3	Potentially vulnerable Refer Section 2.2.4	Unknown, but probably low vulnerability Refer Section 2.2.4	Unknown Refer Section 2.2.5	Unknown Refer Section 2.2.6	Potentially vulnerable Refer Section 2.2.6	Potentially vulnerable Refer Section 2.2.7	Unknown Refer Section 2.2.8	Unknown Refer Section 2.2.9

Table 9. Interaction matrix - vulnerability of the commercial, recreational and scenic values of the Shoalhaven estuary to the range of potential inflow-reduction processes.

The vulnerability assessment in this table refers to discussion and recommendations for the scope of the Detailed Investigative Phase of the methodology. The discussion and recommendations are found in Section 2.2, which immediately follows this table.

Table key: Red text = Potential or possible vulnerability, green text = low vulnerability, blue text = unknown vulnerability, black text = not relevant.						
Inflow-reduction processes	**Commercial values**			**Recreational values**		**Scenic values**
	Productive commercial fisheries		**Scenic features that attract tourists**	**Fishing**	**Water skiing, wake boarding, sailing, rowing, river cruises, swimming, camping, picnicking, bushwalking, bird watching etc.**	**High scenic values that are publicly appreciated**
	Fish, prawns, etc.	**Oysters**				
Low-1: increased hostile water-quality conditions at depth [in upper-middle estuary]	Potentially vulnerable Refer Section 2.2.3	Low vulnerability Refer Section 2.2.3	Low vulnerability	Unknown Refer Section 2.2.3	Low vulnerability	Low vulnerability
Low-2: extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive fauna	Potentially vulnerable Refer Sections 2.2.1 & 2.2.3	Low vulnerability Refer Sections 2.2.1 & 2.2.3	Low vulnerability	Unknown Refer Sections 2.2.1 & 2.2.3	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.1, 2.2.3 & 2.2.4	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.1, 2.2.3 & 2.2.4

Table key: Red text = Potential or possible vulnerability, green text = low vulnerability, blue text = unknown vulnerability, black text = not relevant.						
Inflow-reduction processes	**Commercial values**			**Recreational values**		**Scenic values**
	Productive commercial fisheries		**Scenic features that attract tourists**	**Fishing**	**Water skiing, wake boarding, sailing, rowing, river cruises, swimming, camping, picnicking, bushwalking, bird watching etc.**	**High scenic values that are publicly appreciated**
	Fish, prawns, etc.	**Oysters**				
Low-3: extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive flora	Habitat potentially vulnerable Refer Sections 2.2.1 & 2.2.6	Low vulnerability Refer Sections 2.2.1 & 2.2.3	Low vulnerability	Habitat potentially vulnerable Refer Sections 2.2.1 & 2.2.6	Possible loss of some river amenity from changes in aquatic and riparian vegetation Refer Sections 2.2.1 & 2.2.6	Possible loss of some river amenity from changes in aquatic and riparian vegetation Refer Sections 2.2.1 & 2.2.6
Low-4: extended durations of elevated salinity in the lower estuary allowing the invasion of marine biota	Low vulnerability Refer Sections 2.2.1 & 2.2.3	Potentially vulnerable Refer Sections 2.2.1 & 2.2.3	Low vulnerability	Low vulnerability Refer Sections 2.2.1 & 2.2.3	Low vulnerability	Low vulnerability
Low-5: extended durations when flow-induced currents cannot suspend eggs or larvae [in upper-middle estuary]	Unknown Refer Section 2.2.3	Low vulnerability Refer Section 2.2.3	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.3 & 2.2.4	Unknown Refer Section 2.2.3	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.3 & 2.2.4	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.3 & 2.2.4
Low-6: extended durations when flow-induced currents cannot transport eggs or larvae [in upper-middle estuary]	Unknown Refer Section 2.2.3	Low vulnerability Refer Section 2.2.3	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.3 & 2.2.4	Unknown Refer Section 2.2.3	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.3 & 2.2.4	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.3 & 2.2.4

Table key: Red text = Potential or possible vulnerability, green text = low vulnerability, blue text = unknown vulnerability, black text = not relevant.						
Inflow-reduction processes	**Commercial values**			**Recreational values**		**Scenic values**
	Productive commercial fisheries		**Scenic features that attract tourists**	**Fishing**	**Water skiing, wake boarding, sailing, rowing, river cruises, swimming, camping, picnicking, bushwalking, bird watching etc.**	**High scenic values that are publicly appreciated**
	Fish, prawns, etc.	**Oysters**				
Low-7: aggravation of pollution problems [in upper-middle estuary]	Low vulnerability due to existing low pollution levels	Potentially vulnerable Refer Section 2.2.3	Low vulnerability due to existing low pollution levels	Low vulnerability due to existing low pollution levels	Low vulnerability due to existing low pollution levels	Low vulnerability due to existing low pollution levels
Low-8: reduced longitudinal connectivity with upstream river systems	Potentially vulnerable Refer Section 2.2.3	Unknown Refer Section 2.2.3	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.3 & 2.2.4	Potentially vulnerable Refer Section 2.2.3	Possible loss of some river amenity from changes in river dependent flora and fauna Refer Sections 2.2.1, 2.2.3, 2.2.4 & 2.2.6	Possible loss of some river amenity from changes in river dependent flora and fauna Refer Sections 2.2.1, 2.2.3, 2.2.4 & 2.2.6
Medium/High-1: diminished frequency that the estuary bed is flushed of fine sediments and organic material (physical-habitat quality reduction)	Unknown Refer Section 2.2.3	Potentially vulnerable Refer Section 2.2.3	Low vulnerability	Unknown Refer Section 2.2.3	Low vulnerability	Low vulnerability

Table key: Red text = Potential or possible vulnerability, green text = low vulnerability, blue text = unknown vulnerability, black text = not relevant.						
Inflow-reduction processes	**Commercial values**			**Recreational values**		**Scenic values**
	Productive commercial fisheries		**Scenic features that attract tourists**	**Fishing**	**Water skiing, wake boarding, sailing, rowing, river cruises, swimming, camping, picnicking, bushwalking, bird watching etc.**	**High scenic values that are publicly appreciated**
	Fish, prawns, etc.	**Oysters**				
Medium/High-2: diminished frequency that deep sections of the estuary are flushed of organic material (subsequent water quality reduction)	Unknown Refer Section 2.2.3	Potentially vulnerable Refer Section 2.2.3	Low vulnerability	Unknown Refer Section 2.2.3	Low vulnerability	Low vulnerability
Medium/High-3: reduced channel-maintenance processes	Potentially vulnerable Refer Section 2.2.3	Potentially vulnerable Refer Section 2.2.3	Low vulnerability	Potentially vulnerable Refer Section 2.2.3	Low vulnerability	Low vulnerability
Medium/High-4: reduced inputs of nutrients and organic material	Unknown Refer Section 2.2.3	Potentially vulnerable Refer Section 2.2.3	Low vulnerability	Unknown Refer Section 2.2.3	Low vulnerability	Low vulnerability
All-1: altered variability in salinity structure	Unknown Refer Sections 2.2.1 & 2.2.3	Unknown Refer Sections 2.2.1 & 2.2.3	Low vulnerability	Unknown Refer Sections 2.2.1 & 2.2.3	Low vulnerability	Low vulnerability
All-2: dissipated salinity/chemical gradients used for animal navigation and transport	Potentially vulnerable Refer Sections 2.2.1 & 2.2.3	Unknown Refer Section 2.2.3	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.3 & 2.2.4	Potentially vulnerable Refer Sections 2.2.1 & 2.2.3	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.3 & 2.2.4	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.3 & 2.2.4

Table key: Red text = Potential or possible vulnerability, green text = low vulnerability, blue text = unknown vulnerability, black text = not relevant.						
Inflow-reduction processes	**Commercial values**			**Recreational values**		**Scenic values**
	Productive commercial fisheries		**Scenic features that attract tourists**	**Fishing**	**Water skiing, wake boarding, sailing, rowing, river cruises, swimming, camping, picnicking, bushwalking, bird watching etc.**	**High scenic values that are publicly appreciated**
	Fish, prawns, etc.	**Oysters**				
All-3: decreases in the availability of critical physical-habitat features, particularly the component associated with higher water-velocities	Potentially vulnerable Refer Section 2.2.3	Potentially vulnerable Refer Section 2.2.3	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.3 & 2.2.4	Potentially vulnerable Refer Section 2.2.3	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.3 & 2.2.4	Possible loss of some river amenity from changes in river dependent fauna Refer Sections 2.2.3 & 2.2.4

2.2 Discussion of vulnerability of Shoalhaven estuary values to reduced freshwater inflows

The discussion in this section refers to the vulnerability assessments in Table 8 and Table 9.

2.2.1 Vulnerability of salinity-dependent values

A range of Shoalhaven River estuary values have been identified as being vulnerable or potentially vulnerable to altered estuary salinity resulting from reduced freshwater inflows.

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.

In apparent contrast to the subsequent Independent Expert Panel observations, numerical modelling of the estuary completed in 1996 for Shoalhaven City Council (Lawson and Treloar 1996 pp. 6 & 15) 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".

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 pp. 59 & 61). In an analysis of the data collected by Lawson and Treloar (1996), The Ecology Lab found that the salinity of the Shoalhaven River estuary is likely to be highly variable, particularly in the upper estuary (The Ecology Lab 1996 pp. 35-37). 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 alerts that the impact of freshwater extractions on salinity variability may be ecologically significant for the Shoalhaven, as at least one study (Montague and Ley 1993) has shown that standard deviation of salinity, rather than mean salinity, is a better predictor of the distribution and biomass of estuarine macrophytes and benthic macroinvertebrates. The Ecology Lab also reports that studies have estimated that a freshwater flow in excess of 43,000 ML will be sufficient to achieve total flushing of the estuary, that flushing flows occur on average three times a year, and that it takes 2 to 4 weeks following a major flood before salinity is re-established through the estuary (The Ecology Lab 1996 p. 36).

Step 1 of the Detailed Investigative Phase requires the preparation of a model of flow and salinity within the estuary (see Section 2.3.1). This new modelling is essential to resolve the current lack of clarity in regard to the salinity regime in the Shoalhaven River estuary and the impacts of current and proposed increased water transfers on that regime. The Hawkesbury-Nepean River Management Forum Independent Expert Panel has also recommended that detailed numerical modelling of the estuary be carried out in association with examining the inflow/salinity responses of ecological indicators (IEP 2003). The new modelling should use the new bathymetric (river bed) data being compiled in 2005-2006 by DNR.

Recommendation A: That new flow and salinity modelling of the Shoalhaven River estuary, as required in Step 1 of the Detailed Investigative Phase, is essential to resolve the current lack of clarity in regard to the salinity regime in the Shoalhaven River estuary and the impacts of current and proposed increased water transfers on that regime. The new modelling needs to be carried out in association with examining the inflow/salinity responses of ecological indicators, and should investigate the impact of freshwater extraction on the low salinity zone of the estuary, on the variability of the salinity regime and on the volume and frequency of flushing flows. The modelling should use the new bathymetric (river bed) data being compiled in 2005-2006 by DNR.

2.2.2 Vulnerability of threatened fish species - Australian Grayling

The Shoalhaven River has special significance for fish conservation because it has provided permanent habitat for the Australian Grayling (*Prototroctes maraena*), which is listed as a Vulnerable species under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (DEH 2004). However, recent surveys have collected only a single specimen from the Shoalhaven system downstream of Tallowa Dam (Coysh *et al.* 2005 p. 34).

The primary cause of decline of this species in the Shoalhaven River system is the physical obstruction to migration presented by Tallowa Dam (DEH 2004). However, loss of dry weather stream flow and suppression of minor flooding could also be reasons for decline (DEH 1993).

The Australian Grayling spawns in freshwater in early February to early March, and it is suggested that an increase in river discharge to a critical level is required to trigger spawning. There is speculation that eggs settle in the crevices of the gravel bottom, and larvae probably drift downstream. The newly hatched fry are presumably swept downstream to brackish water in estuaries or to the ocean where they remain for around six months. During November juveniles then ascend to the mid-reaches of the river where they spend the rest of their lives. Larval and juvenile Grayling have never been reported from typical estuarine waters, nor have eggs or newly hatched larvae been collected from the freshwater reaches of rivers. (DEH 2004).

Extensive stream siltation and the alteration, particularly through siltation, of stream macroinvertebrate communities that provide food have been identified as reasons for species decline (DEH 1993). However the species has been recorded in muddy-bottomed, heavily silted and high turbidity habitats (DEH 2004).

The environmental flow factors identified for the Australian Grayling appear to be related to freshwater river reaches, with the exception of estuary salinity. Any impacts of elevated salinity would be dependant on exactly where egg development and larval stages occur, as salinities higher than five parts per thousand (5 ppt) were unfavourable for normal egg development, but once hatching occurs the larvae can tolerate salinities up to 30 ppt (DEH 2004).

Recommendation B: That the Detailed Investigative Phase considers the vulnerability of Australian Grayling eggs and hatchlings to altered estuary salinity resulting from reduced freshwater inflows.

2.2.3 *Vulnerability of other fish, commercial fishery species, and oysters*

A Multiple Lines and Levels of Evidence (MLLE) assessment carried out by the CRC for Freshwater Ecology indicates that for determining effects related to flow volume, most support in the literature is available for fish and macroinvertebrates (Coysh *et al.* 2005 p. 72).

A 2002 study of the relationships between river flows and commercial fish catches in the Hawkesbury-Nepean and Shoalhaven River systems (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 components of the flow regime, there remains uncertainty around which aspects of the hydrological regime influenced each species because the majority of hydrological variables are highly correlated.

One species for which more information is available is the Australian Bass (*Macquaria novemaculeata*), which is an iconic species in terms of recreational fishing. This is the species on which the current Shoalhaven River environmental flow of up to 90 ML/day was based, and its flow requirements are again being considered as part of the Physical Habitat Modelling investigation (Boyes 2006b p. 35) and Fish Passage Study investigation (Boyes 2006b p. 36). Australian Bass migrate downstream to estuaries to breed between May and August (NSW Fisheries 2005), where successful breeding appears to require water salinity levels of between 12 and 15 ppt (Barnham 1998).

Information is also available for oysters, which 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). The general conditions required for growing healthy oysters are well oxygenated, clear, and brackish to saline waters, with pH in the range 6.75 to 8.75, suitable tidal exchange, adequate phytoplankton supplies and control of upstream sources of runoff and pollution (HRC 2003 p. 5). The extraction of freshwater upstream during low flow periods constitutes a threat to growing healthy oysters, as does pollution from point and non-point sources (HRC 2003 p. 9). Oyster embryos are markedly affected by acid sulfate soil drainage (Wilson and Hyne 1997), so concerns about potential acid sulfate soil drainage have been expressed by growers in the Shoalhaven.

Sydney rock and Pacific oysters have different salinity requirements (HRC 2003 p. 19). The Pacific oyster can tolerate salinities ranging from 11 to 48 ppt and can grow in fully marine waters. Sydney rock oysters grow in fresher conditions than Pacific oysters and salinities below 30-35 ppt appear optimal. Because of this, increased estuary salinity levels from reduced freshwater inflows could lead to Pacific oysters gaining a competitive advantage. In the 1980's, the introduction of non-native Pacific oysters led to dramatic declines in the production of native Sydney rock oysters in

Port Stephens, and since then, NSW Fisheries have prohibited their farming into other estuaries (HRC 2003 pp. 21-22).

The Flora and Fauna Review investigation (see Section 1.1.3) may reveal other fish or commercial fishery species of interest or significance that may be vulnerable to altered estuary salinity resulting from reduced freshwater inflows.

Recommendation C: That the Detailed Investigative Phase considers:

- ***the vulnerability of Australian Bass breeding to altered estuary salinity resulting from reduced freshwater inflows;***
- ***the vulnerability of Sydney rock oysters to altered estuary salinity resulting from reduced freshwater inflows;***
- ***the vulnerability of other fish species of interest or significance identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows; and***
- ***the vulnerability of Sydney rock oysters to altered estuary water quality resulting from reduced freshwater inflows.***

2.2.4 Vulnerability of other river dependant fauna

The CRC for Freshwater Ecology recommends investigation into the flow requirements of other river dependant fauna such as platypus, turtles, water rat and frogs (Coysh *et al.* 2005 p. 11).

Platypus (*Ornithorhynchus anatinus*) may be present below Tallowa Dam (Woodford 2004), and possibly in the upper estuary. If platypus are present in the upper estuary, it is unlikely they remain there for long periods if salinity levels are high (see Section 2.2.1 above). The Australian Platypus Conservancy *Platypus Conservation Guidelines* advise that while platypus are occasionally seen in the tidal reaches of rivers, they are basically adapted to live in freshwater environments (Australian Platypus Conservancy undated). For example, it has been suggested that the platypus electro-receptor system may not function very effectively in highly saline water. Inputs of salt can drastically alter the ecology of streams, lakes and rivers, with many species of freshwater invertebrates unable to tolerate saline conditions. In particular, the productivity of pool habitats is likely to be reduced substantially by high salinity levels, because salty water is both denser and holds less dissolved oxygen than freshwater.

Scott & Grant (1997) reviewed the habitat requirements of the platypus 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 & 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 available information shows that further information is needed regarding the presence/absence of platypus populations below Tallowa Dam, and that the vulnerability of any identified populations needs to be considered. The Flora and Fauna Review investigation (see Section 1.1.3) will assist in this regard.

The Green & Golden Bell Frog (*Litoria aurea*), which is listed as an Endangered Species on Schedule 1 of the New South Wales *Threatened Species Conservation Act 1995* (TSC Act), is found in wetlands in the Shoalhaven Estuary (see Sections 2.2.7 and 2.2.9 below). No location-specific information is currently available in regard to other frog species, the water rat, or turtles. However, the Flora and Fauna Review investigation (see Section 1.1.3) may reveal further information.

Scott & Grant (1997) reviewed the habitat requirements of the water rat in relation to water management practices in the Murray-Darling basin, and found it to be an opportunistic species with a high degree of adaptability to varied conditions in a wide range of habitats. Very little is known of the salinity tolerance of Australian frog species, but, in general, frogs are not adapted to life in saline environments (DLWC 1999).

Recommendation D: ***That the Detailed Investigative Phase:***

- ***considers the vulnerability of other river dependant fauna identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows; and***
- ***should not consider the vulnerability of the water rat, as it is an opportunistic species with a high degree of adaptability to varied conditions in a wide range of habitats.***

2.2.5 Vulnerability of macroinvertebrates

As stated in Section 2.2.3, a Multiple Lines and Levels of Evidence (MLLE) assessment carried out by CRC for Freshwater Ecology indicates that for determining effects related to flow volume, most support in the literature is available for fish and macroinvertebrates (Coysh *et al.* 2005 p. 72).

There is limited macroinvertebrate data available for the Shoalhaven River estuary. The Ecology Lab (1993a, 1993b) surveyed benthic 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 and crustaceans. Another study undertaken by The Ecology Lab (1995) sampled benthic macroinvertebrates in the lower estuary. 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 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.

The Flora and Fauna Review investigation (see Section 1.1.3) may reveal further macroinvertebrate information.

Recommendation E: ***That the Detailed Investigative Phase considers the vulnerability of estuary macroinvertebrate species to altered estuary salinity resulting from reduced freshwater inflows, using information from the Flora and Fauna Review investigation and the studies conducted by The Ecology Lab.***

2.2.6 Vulnerability of aquatic and riparian vegetation

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) and concluded 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 pp. 39-40). However, as discussed in Section 2.2.1, there is currently a lack of clarity in regard to the impact of water transfers on estuary salinity. As stated in Recommendation A, flow and salinity modelling is required to resolve this lack of clarity.

Changes in the distribution of aquatic plants have also occurred in the lower estuary. The Shoalhaven River Estuary Data Compilation Study reports changing patterns of distribution for mangrove (*Avicennia marina*), saltmarsh and seagrass (*Zostera* sp.), however these changes are not attributed to altered flow regimes as a result of Tallowa Dam (Umwelt 2005 pp. 9.5-9.6).

The CRC for Freshwater Ecology (Coysh *et al.* 2005 p. 41) reports that riparian weed species have been observed growing within the river channel of the estuary and lower on the shore, and casuarinas were present higher on the banks. Downstream in the lower estuary, 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. This degradation has enhanced bank slumping and erosion. In addition, many of the lateral wetlands that were once present in this reach have been drained.

The Flora and Fauna Review investigation (see Section 1.1.3) may reveal aquatic and riparian vegetation of interest or significance that may be vulnerable to altered estuary salinity resulting from reduced freshwater inflows.

Recommendation F: ***That the Detailed Investigative Phase considers the vulnerability of aquatic and riparian vegetation of interest or significance identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows.***

2.2.7 Vulnerability of floodplain wetlands

Flood mitigation measures undertaken mainly in the 1960s have considerably reduced the area of floodplain wetlands. These involved levee repair and floodgates on tributaries restricting flooding from the river until levees are topped (at lower frequencies than back-up floods through tributaries). After flooding, drainage evacuates excess water through floodgates, which are opened at low tides. Only the largest floods can now connect with wetlands temporarily. (Coysh *et al.* 2005 p. 54).

Flow events sufficiently large to maintain ephemeral freshwater ponds on the floodplain are a significant life cycle requirement of many frogs including the Green & Golden Bell Frog (*Litoria aurea*) which is listed as an Endangered Species on Schedule 1 of the New South Wales *Threatened Species Conservation Act 1995* (TSC Act) and found in wetlands in the Shoalhaven Estuary (pers. comm. Chris Rush, Department of Environment and Conservation). The ephemeral nature of the ponds importantly reduces predation of eggs and tadpoles by fish (notably Bass and Gambusia), but the ponds should remain filled for at least 5-6 weeks (Goldingay and Newell 2005). However, it is not known to what extent the ephemeral freshwater ponds on the floodplain are dependent on flood flows directly from the river, and to what extent they are dependant on other non-river surface flows.

Recommendation G: That the Detailed Investigative Phase includes investigation to determine:

- ***which of the ephemeral freshwater ponds on the floodplain are dependent on flood flows directly from the river; and***
- ***the vulnerability of any identified wetlands to altered estuary conditions resulting from reduced freshwater inflows.***

2.2.8 Vulnerability of JAMBA/CAMBA waterbird species

The flow requirements of migratory waterbird species covered by the China-Australia Migratory Bird Agreement (CAMBA) and Japan-Australia Migratory Bird Agreement (JAMBA) are being addressed by the Flora and Fauna Review investigation (see Section 1.1.3). Initial investigations show that there are a number of JAMBA/CAMBA waterbird species present in the estuary study area, and that most or all of these species are dependant on riparian habitat, floodplain wetlands and/or coastal habitat near the estuary mouth (NPWS 2005b, DEH 2005c). Because of this, it is possible that they may be affected by reduced freshwater inflows.

Recommendation H: That the Detailed Investigative Phase considers the vulnerability of China-Australia Migratory Bird Agreement (CAMBA) and Japan-Australia Migratory Bird Agreement (JAMBA) species identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows.

2.2.9 Vulnerability of threatened riparian and floodplain species and ecological communities

The flow requirements of threatened riparian and floodplain species and ecological communities are being addressed by the Flora and Fauna Review investigation (see Section 1.1.3). Initial investigations show that a number of threatened species and ecological communities are present (Umwelt 2005 p. 10.1, NPWS 2005a), and that at least some of these species are likely to be affected by altered flows, for example the Endangered Green & Golden Bell Frog (*Litoria aurea*) as discussed in Section 2.2.7 above.

Recommendation I: That the Detailed Investigative Phase considers the vulnerability of threatened riparian and floodplain species and ecological communities identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows.

2.2.10 Vulnerability of water quality in the middle-upper estuary

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 (IEP 2004 p. 33). Deep pools occur in the upper Shoalhaven River estuary (pers. comm. John Floyd, Estuaries Group, DNR), and while stratification of these pools could occur naturally, the frequency, duration and magnitude of stratification events could be exacerbated by prolonged periods of reduced freshwater inflow caused by transfers from Tallowa Dam to the Hawkesbury-Nepean River System (IEP 2004 p. 33). 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 freshwater.

Recommendation J: That the Detailed Investigative Phase considers the flushing flows needed to flush all saline water from the deep pools in the upper estuary.

2.3 Detailed Investigative Phase

The recommendations in Section 2.2 inform the Detailed Investigative Phase of the methodology. The process of this phase is explained below (Peirson *et al.* 2002).

2.3.1 DIP Step 1: Apply catchment runoff and estuarine flow models

The methodology advises that studies must be undertaken to understand the present estuarine physical, chemical, water quality and sediment transport/geomorphological behaviour. Initially, two compatible numerical models need to be prepared:

1. A model of catchment runoff to the estuary including water extraction.
2. A model of flow and salinity within the estuary.

SCA has already developed a catchment runoff model that can provide 105 years (1900 to 2004) of daily inflow into the estuary for a range of extraction and environmental flow scenarios, meaning that only flow and salinity modelling needs to be developed. As discussed in Section 2.2.1 this modelling is essential, and it is important that it can be used to predict the salinity structure over a long period so that impact of both flood and drought dominated regimes can be represented in the assessment.

If required, additional desktop calculations or modelling can be used to assess water quality, sediment transport behaviour and geomorphological change. Because of the limited availability of information, assessments relating to water quality, sediment transport behaviour and geomorphological change for the Shoalhaven River estuary are likely to instead need to be done qualitatively.

2.3.2 DIP Step 2: Define environmental flow scenarios for the estuary

In this step of the methodology, extraction and environmental flow scenarios for the Shoalhaven River estuary are defined.

2.3.3 DIP Step 3: Use the models to assess the impact of proposed scenarios

This step of the methodology involves using the environmental flow scenarios defined at DIP Step 2 to run model simulations to assess the impact on estuary salinity.

2.3.4 DIP Step 4: Assess the risk to estuarine values

At this step, the results of DIP Step 3 and the outcomes of the assessments in Sections 2.1.4 and 2.2 are used to assess the risk to estuarine values from the defined environmental flow scenarios.

As part of this step, salinity thresholds for the various ecological values described in Sections 2.1.4 and 2.2 need to be compiled. Table 10 shows an example of the use of indicative salinity thresholds to assist in assessing the risk to estuarine values, in this case for the Hawkesbury-Nepean estuary (Cox and Peirson 2003 p. 7) (please note that Table 10 is provided only to illustrate how salinity thresholds can be used, and the information in the table is not necessarily relevant to the Shoalhaven River estuary).

Table 10. An example of the use of indicative salinity thresholds to assist in assessing the risk to estuarine values, in this case for the Hawkesbury-Nepean estuary. (Source: Cox and Peirson 2003 p. 7).

Ecosystem Facet	Salinity	Biological Significance	Quantity Measure
1	< 0.5 ppt	• upper limit for platypus (indirect impacts) • very high salt sensitive freshwater-associated algae	Estuary length and area
2	< 1.0 ppt	• the maintenance of freshwater ecosystems • maximum biomass of *Egeria densa* • high salt sensitive freshwater-associated macrophytes • high salt sensitive freshwater-associated algae • lowest (recorded) limit for school prawns	Estuary area
3	< 2.5 ppt	• approx. one third biomass of *Egeria densa* • high-moderate salt sensitive freshwater-associated macrophytes • approx. lower limit (3 ppt) for juvenile king prawns	Estuary area
4	< 5.0 ppt	• upper limit for adult Australian bass outside of the spawning season • absolute upper limit for *Egeria densa* • moderate salt sensitive freshwater-associated macrophytes • moderate salt sensitive freshwater-associated algae	Estuary area
5	< 7.5 ppt	• low-moderate salt sensitive freshwater-associated macrophytes • approx. lower limit (7 ppt) for adult king prawns	Estuary area
6	> 8.0 ppt	• lower limit for adult Australian bass during the spawning season	Estuary area
7	< 10 ppt	• low salt sensitive freshwater-associated macrophytes • low salt sensitive freshwater-associated algae	Estuary area
8	< 13 ppt	• upper limit for adult Australian bass during the spawning season	Estuary area
9	< 20 ppt	• Sydney rock oyster - winter mortality • Sydney rock oyster - marine fouling of substrates	Estuary length

2.3.5 DIP Step 5: Specification of environmental flow regime

Once the values risk analysis (DIP Step 4) is complete, an appropriate environmental flow regime for the estuary can be specified and/or risk management strategies for particular values developed.

2.3.6 DIP Step 6: Adaptive management

The foundation of the Peirson *et al*. (2002) methodology is good information regarding estuary behaviour and ecological characteristics. However, Peirson *et al.* (2002) are aware that more research is required before the ecological health of Australian estuaries can be accurately and cost-effectively assessed. They advise that adaptive management will be required, and this is also the advice of the CRC for Freshwater Ecology (Coysh *et al.* 2005 pp. 73-80).

3. Conclusions and recommendations

The Estuary Modelling and Assessment investigation has used a methodology developed through the Environmental Flows Initiative of the National River Health Program. The methodology is described in the Environmental Flows Initiative report, 'Environmental Water Requirements to Maintain Estuarine Processes' (Peirson *et al.* 2002), and is composed of two phases: a 'Preliminary Evaluation Phase' and a 'Detailed Investigative Phase'. The Preliminary Evaluation Phase aims to yield a classification of estuaries by significance and risk as well as the scope of more detailed investigative programs. The purpose of the Detailed Investigative Phase is to determine an appropriate level of environmental freshwater flow for any given estuary.

The Preliminary Evaluation Phase of the methodology has been carried out for the Shoalhaven River estuary. The results of the Preliminary Evaluation Phase are documented in this paper, and include:

- a values assessment of the Shoalhaven River estuary (see Table 4);
- an assessment of inflow variables for the Shoalhaven River estuary, changes due to human activity, and the magnitude of these changes (see Table 5 and Section 2.1.3); and
- an assessment of the vulnerability of the valued components of the Shoalhaven River estuary to a range of potential inflow-reduction processes (see Table 8 and Table 9).

From these results, recommendations for the scope of the Detailed Investigative Phase for the Shoalhaven River estuary are made. The recommendations are:

A. That new flow and salinity modelling of the Shoalhaven River estuary, as required in Step 1 of the Detailed Investigative Phase, is essential to resolve the current lack of clarity in regard to the salinity regime in the Shoalhaven River estuary and the impacts of current and proposed increased water transfers on that regime. The new modelling needs to be carried out in association with examining the inflow/salinity responses of ecological indicators, and should investigate the impact of freshwater extraction on the low salinity zone of the estuary, on the variability of the salinity regime and on the volume and frequency of flushing flows. The modelling should use the new bathymetric (river bed) data being compiled in 2005-2006 by DNR.

B. That the Detailed Investigative Phase considers the vulnerability of Australian Grayling eggs and hatchlings to altered estuary salinity resulting from reduced freshwater inflows.

C. That the Detailed Investigative Phase considers:
   - the vulnerability of Australian Bass breeding to altered estuary salinity resulting from reduced freshwater inflows;
   - the vulnerability of Sydney rock oysters to altered estuary salinity resulting from reduced freshwater inflows;
   - the vulnerability of other fish species of interest or significance identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows; and
   - the vulnerability of Sydney rock oysters to altered estuary water quality resulting from reduced freshwater inflows.

D. That the Detailed Investigative Phase:
   - considers the vulnerability of other river dependant fauna identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows; and

- should not consider the vulnerability of the water rat, as it is an opportunistic species with a high degree of adaptability to varied conditions in a wide range of habitats.

E. That the Detailed Investigative Phase considers the vulnerability of estuary macroinvertebrate species to altered estuary salinity resulting from reduced freshwater inflows, using information from the Flora and Fauna Review investigation and the studies conducted by The Ecology Lab.

F. That the Detailed Investigative Phase considers the vulnerability of aquatic and riparian vegetation of interest or significance identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows.

G. That the Detailed Investigative Phase includes investigation to determine:
   - which of the ephemeral freshwater ponds on the floodplain are dependent on flood flows directly from the river; and
   - the vulnerability of any identified wetlands to altered estuary conditions resulting from reduced freshwater inflows.

H. That the Detailed Investigative Phase considers the vulnerability of China-Australia Migratory Bird Agreement (CAMBA) and Japan-Australia Migratory Bird Agreement (JAMBA) species identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows.

I. That the Detailed Investigative Phase considers the vulnerability of threatened riparian and floodplain species and ecological communities identified in the Flora and Fauna Review investigation to altered estuary salinity resulting from reduced freshwater inflows.

J. That the Detailed Investigative Phase considers the flushing flows needed to flush all saline water from the deep pools in the upper estuary.

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