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Estuary Environmental Flows Assessment Methodology

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FINAL DRAFT
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Table of Contents

1 EXECUTIVE SUMMARY 6
  1.1 BACKGROUND 6
  1.2 OBJECTIVES 6
  1.3 SCOPE 6
  1.4 APPLICATION 7

2 INTRODUCTION 9
  2.1 BACKGROUND AND CONTEXT 9
  2.2 PROJECT OBJECTIVES 10
  2.3 PROJECT TEAM 10
  2.4 PILOT STUDIES AND METHOD REFINEMENT 11

3 VICTORIAN WATER ALLOCATION POLICY AND PRACTICE 13
  3.1 LEGISLATION 13
  3.2 PLANNING 13
  3.3 ENVIRONMENTAL WATER RESERVE PLANNING TOOLS 14

4 EEFAM COMPONENTS AND CONCEPTS 16
  4.1 PREAMBLE 16
  4.2 EEFAM OBJECTIVES 16
  4.3 ESTUARY DEFINITION (STUDY AREA) 18
  4.4 FLOW COMPONENTS 18
  4.5 EEFAM PROJECT TEAM 22
  4.6 ASSET-BASED APPROACH 24
  4.7 CONCEPTUAL MODELS 25
  4.8 TRANSLATING HABITAT REQUIREMENTS TO HYDROLOGICAL AND HYDRAULIC THRESHOLDS 31
  4.9 HYDROLOGICAL ANALYSIS AND HYDRODYNAMIC MODELLING 34
  4.10 MINIMUM DATA REQUIREMENTS 35
  4.11 ASSUMPTIONS AND LIMITATIONS OF THE METHOD 35

5 EEFAM SPECIFICATION 36
  5.1 STEP 1. PROJECT ESTABLISHMENT 37
  5.2 STEP 2. CHARACTERISATION OF PHYSICAL ESTUARY ENVIRONMENT 38
  5.3 STEP 3. SITE PAPER 44
  5.4 STEP 4. EEFTP SITE INSPECTION AND WORKSHOP 48
  5.5 STEP 5. ISSUES PAPER 49
  5.6 STEP 6. MODEL INTERROGATION 51
  5.7 STEP 7. SCIENTIFIC PANEL WORKSHOP 51
  5.8 STEP 8. ENVIRONMENTAL WATER MANAGEMENT RECOMMENDATIONS 52
  5.9 STEP 9. FINAL REPORT AND PRESENTATION TO STAKEHOLDERS 52

6 REFERENCES 55

1 APPENDICES 58
  A. INFORMATION SOURCES FOR ESTUARY FLOWS STUDIES 58
  B. KEY DOCUMENTS, POLICIES, STRATEGIES AND PLANS WHICH WOULD BE USEFUL FOR SETTING THE STRATEGIC CONTEXT TO EVERY ESTUARY FLOWS STUDY INFORMATION 59
Please cite as follows:

Abbreviations
CCC – Community Consultative Committee
CMA – Catchment Management Authority
DSE – Department of Sustainability and Environment
EEFTP – Estuary Environmental Flows Technical Panel
EEFAM – Estuary Environmental Flows Assessment Methodology
EEFAR – Estuary Environmental Flows Assessment Report
EEMSS – Estuary Entrance Management Support System
EVC - Ecological Vegetation Class
EWR – Environmental Water Reserve
FLOWS – Victorian statewide method for environmental water requirements determinations in rivers
IAN - Integration and Application Network University of Maryland’s Center for Environmental Science (see http://ian.umces.edu/).
SC – Steering Committee
SDL – Sustainable Diversion Limit
VRHS - Victorian River Health Strategy
1 EXECUTIVE SUMMARY

1.1 Background

This report sets out a method to determine the environmental water requirements of estuaries in Victoria. The Estuary Environmental Flows Assessment Method, termed EEFAM, is a standard methodology which is available to be applied in a consistent manner across all major Victoria estuaries.

EEFAM is derived from FLOWS, the Victorian statewide method for environmental water requirement determinations in rivers. The list of tasks has been modified and re-ordered in EEFAM to reflect the environmental and management issues specific to estuaries, particularly the role of salinity, water residence time, stratification, estuary entrance opening and tides. EEFAM and FLOWS can be applied simultaneously to a river and its estuary to a whole of system approach to environmental flow requirements.

1.2 Objectives

The primary objective of EEFAM is to define a flow regime which will maintain the ecological health of an estuary. A healthy estuary is defined as one which retains the major ecological features and functioning of the estuary prior to European settlement and can sustain these features in the future.

The role of EEFAM is to build a recommended inflow hydrology, or flow regime, from the known dependency of flora, fauna, biogeochemical and geomorphological features on flow. EEFAM is an evidence-based methodology, where the flow regime is comprised of a set of flow components to which specific, environmental outcomes can be attributed. This bottom-up or 'building block' approach conforms with the asset based approach of the Victorian River Health Strategy.

1.3 Scope

EEFAM is implemented by an Environmental flows Technical Panel (EEFTP) of experts in hydrology, hydraulic modelling, physical estuarine limnology, geomorphology and habitat structure/diversity, freshwater and marine plant ecology, fish and macro-invertebrate ecology and geomorphology. Depending on the particular estuary, expertise may also be required in hydrogeology and waterbird ecology. The panel is guided by a Steering Committee with input from a Community Consultative Committee.

The flora, fauna and geomorphological features used to develop flow recommendations are termed environmental assets. The assets are selected from all the possible features in the estuary on the basis that they:

- jointly represent the requirements of all other important environmental features and processes;
- jointly represent the water requirements of the important conservation values of the estuary;
- are sufficiently well-understood to support evidence-based environmental flow recommendations;
- provide requirements for a wide range of flow events and estuary entrance states.

Conceptual models are developed for each asset to describe how they depend on flow. A library of conceptual models will be maintained and can be drawn on during each estuary study. Each
model will have a universal component, which documents scientific knowledge generally believed to be applicable to most estuaries, and a local component which is applicable to the estuary in question. Environmental objectives will be set for the flow-dependent assets of the conceptual models. The intention of the objectives is that together they represent the achievement of a healthy estuary.

The hydrological conditions which support the environmental objectives are specified as hydrological objectives. Recommendations to achieve these objectives are developed through the interrogation of a hydrodynamic estuarine model and an analysis of estuary inflow hydrology.

Two hydraulic models are required. A simple 1-dimensional Flood Model is used to determine the flows required to achieve a range of water levels on the floodplain. A complex 2-dimensional vertical slice Tide Model is used to describe the estuary at sub-bankfull levels. This model describes the movement of water and the salt profile in response to riverine inflow, tide and exchange at the estuary entrance.

These models and the hydrological analysis are used to report the circumstances under which the hydrological objectives are met including the tide level, season, frequency and duration. Through a workshop process the expected requirements of the environmental assets are aligned with the actual behaviour of the estuary to develop recommendations for the required estuary inflow regime.

1.4 Application

A standard process to complete these tasks has been developed.

Step 1. Project Establishment.

The Steering Committee develops a detailed scope of work and appoints the EEFTP. The Community Consultative Committee is convened.

Step 2. Characterisation of the Physical Estuary Environment.

The hydraulic modeller, estuary limnologist and hydrologist collect data to support a hydrodynamic model. This includes measurements of estuary entrance behaviour, salinity and dissolved oxygen, stratification, water level gauging and physical survey.

The hydraulic models are developed. The Flood Model quantifies the bankfull capacity of the estuary channel and determines approximate flood levels through the estuary. The Tide Model is used to provide a series of standard scenarios which represent a preliminary sensitivity analysis of estuary tidal dynamics and salinity structure to different inflow discharges.

The hydrological characterisation is completed. The analysis summarises the daily flow data so that the EEFTP can conceptualise the basic hydrological type of estuary under investigation, and the range of magnitudes, frequencies and durations of events typical of the estuary.

When groundwater investigations are included in the study, data is collected on the depth, salinity, stratification and hydraulic gradients of groundwater affecting flow-dependent assets.

Step 3. Site Paper

The ecological scientists review existing information on the flora and fauna of the estuary and present a summary of this information in a Site Paper. Conceptual models to be used in the study are identified.

Step 4. EEFTP Site Inspection and Workshop

Panel representatives meet with the Community Consultative Committee to present the scope of
the project, to learn of local stakeholder interests and values in the estuary and to gain access to locally-held information.

The whole EEFTP inspects the estuary and is briefed on the findings of the physical characterisation. The panel identifies and discusses important physical features and hydrological, hydraulic, water quality, groundwater relationships with ecology and geomorphology.

A workshop is held to document these relationships and to plan the analyses which will support the Issues Paper.

**Step 5. Issues Paper**

Conceptual models are prepared for each of the required environmental assets. Peirson et al, 2002, processes are used to identify the physical parameters which regulate the environmental objectives. The hydrological conditions which support the environmental objectives are set as hydrological objectives.

At an internal workshop, the ecological and hydrological objectives are presented. Agreement is reached between the ecologists and physical scientists on the most appropriate parameters to measure the hydrological objectives and the thresholds to evaluate their achievement. The hydraulic modeller and hydrologist agree on how to integrate their data to provide the required information.

**Step 6. Model Interrogation**

The hydraulic modeller prepares the scenarios to determine the conditions under which critical ecological water requirement thresholds are met. The hydrologist performs the statistical analyses required to report timing, frequency and duration of flow events (expressed as discharge volumes) of interest.

**Step 7. EEFTP Flow Recommendations Workshop**

The EEFTP is convened for a final time. The hydrological objectives required to achieve agreed estuarine conditions are reviewed. The frequency, timing and duration with which these conditions are provided are aligned with ecological requirements to develop recommendations which reflect known habitat requirements and the behaviour of the estuary. On this basis, recommendations are made for an inflow regime which supports the ecological objectives and achieves estuary health.

**Step 8. Environmental Water Management Recommendations**

The hydrological and hydraulic analyses, together with the flow recommendations and their justification, are appended to the Issues Paper to form the final report.

**Step 9. Reporting and Presentation to Stakeholders**

Following review of the flow recommendations, the report is finalised. Presentations are made to the Steering Committee and Community Consultative Committee of the findings of the study.

Implementation of the results in Victoria, are subject to the environmental water management recommendations being considered during water planning processes such as stream flow management plans and sustainable water strategies. During these processes, negotiations are made about the flow sharing needs of the environmental and other water users. This process is outside the scope of the method.
2 INTRODUCTION

This report provides a consistent and systematic approach to the determination of environmental water requirements for estuaries in Victoria.

Victoria’s limited water resources are subject to competing demands. These demands, including town water supplies and irrigation requirements, often deplete the flow entering estuaries and put their environmental values at risk.

The Estuary Environmental Flows Assessment Methodology (EEFAM) is a standard methodology which can be applied in a consistent manner across all Victorian estuaries, according to their priority. It is not anticipated that this method would be used for the Gippsland Lakes or Port Phillip or Western Port Bay.

2.1 Background and Context

There is no existing accepted method to determine the required input of freshwater flows into estuaries in Victoria. A draft method (Hardie et al. 2006) was developed as an extension of the FLOWS methodology (NRE 2002b). “FLOWS” is the accepted state-wide method for the determination of environmental water requirements for rivers. It is an objective-based, multi-disciplinary, rigorous approach based upon the holistic Building Block Methodology (King and Louw 1998).

While the dependence of estuaries on stream flow has similarities with the flow dependencies of riverine ecosystems addressed by FLOWS, there are important differences which require a somewhat different approach.

In streams riverine discharge is the variable required to predict water level and velocity through specified channel cross-sections. In contrast water levels in an estuary are controlled by the complex interaction of freshwater inflow as well as marine exchange involving tides, and storm surges which depends on the cross-sectional area of the estuary entrance.

Streams are generally considered to be freshwater systems (i.e. salinity <5g/l), whereas salinity is an important flow-dependent variable in estuaries. Distribution of salinity profiles throughout an estuary is dependent on riverine inflow and other variables such as wind velocity and tidal currents which together determine the effectiveness of turbulent mixing. Understanding and modelling salinity structure is an important component of the evaluation of estuary water requirements.

To a greater degree than in streams, plant communities and faunal assemblages are frequently common across different estuaries in Victoria. There is scope to incorporate consistent approaches to the determination of their water requirements, thereby increasing the scope to share information between studies and so gradually improve knowledge of these ecosystems and their flow dependencies.

River discharge is an important but not the sole determinant of whether an estuary mouth remains open. Other factors that may influence mouth state include changes in astronomical tidal amplitude during the spring-neap tidal cycle and changes in sea level due to atmospheric pressure, wind speed and direction and wave height (known as the meteorological tide). These all directly affect the energy of ocean water and its ability to shift sand along the coast. Wave energy is able to resuspend sand and currents then transport it. Once the water velocity drops (as when seawater enters an estuary entrance or travels up a beach face as wave swash) its capacity to hold sand in suspension decreases and the sand is deposited. On Southwest
Victoria’s micro-tidal coast even small changes in sea level or wave height can cause significant changes in the location of sand deposition zones (Sherwood et al. 2003).

The principal differences between FLOWS and EEFAM are therefore that the latter requires:

- a modified sequencing of major tasks to enable vital information to be gathered;
- a more complex hydrodynamic modelling approach;
- an additional scientific panel workshop to establish hydrological and ecological objectives;

and,

- a library of conceptual models for ecosystem water requirements to share data between estuarine studies and improve knowledge.

2.2 Project Objectives

The initial project brief for the draft estuary flows method project (which established the scope for the current project) called for, similar to the FLOWs method (NRE, 2002), the method to be:

- Generally applicable state wide
- Completed within twelve months
- Scientifically defensible and repeatable
- Have a budget around $70,000 per system, not including hydrological data

The development of the draft method and application of the pilot studies have confirmed that the consultancy costs to undertake an EEFAM assessment using the draft method on a small to intermediate sized estuary is more likely to be closer to $80,000 to $110,000 in 2008. The method as specified in this report (at these investment levels in 2008) will include hydrological, ecological and physical condition assessment of the estuary with detailed hydraulic model but it expects inputs of base hydrological, water quality and water level data. The increase in budget for an EEFAM study is due largely to the need for a slightly larger scientific panel and complex modelling.

2.3 Project Team

The project was supported by an interagency steering committee that contributed to the project and ensured the project objectives were achieved, these included:

- Simone Wilkie (Corangamite CMA), Agency Project Manager
- Paulo Lay (Project Manager), Michaela Dommisse and Bill O'Connor (DSE)
- Jamie Ewert, Cheryl Edwards and Rebecca Johnstone (Melbourne Water)
- Eleisha Keogh (West and East Gippsland CMAs)
- Kylie Bishop and Johanna Theilemann (Glenelg Hopkins CMA)

The project team was comprehensive and experienced with the scientific panel made up of:

- Mr Lance Lloyd (Lloyd Environmental), Estuary FLOWS Project Co-ordinator; fish and aquatic fauna ecologist;
- Dr Marcus Cooling (Ecological Associates), aquatic and floodplain vegetation ecologist;
Dr Chris Gippel (Fluvial Systems), environmental flow and geomorphology specialist;
Dr Brett Anderson (Water Technology), hydrologist and hydraulic modeller;
Associate Professor John Sherwood (Deakin University), estuarine environmental flow scientist (water quality and estuarine processes);
Dr Adam Pope (Deakin University), estuarine water quality and processes scientist;
Dr Jeremy Hindell (DSE, Arthur Rylah Institute), estuarine fish ecologist;
Mr John Leonard (John Leonard Consulting Services), hydrogeologist and environmental scientist;
Dr Phillip Macumber (Phillip Macumber Consulting Services), hydrogeologist and geomorphologist; and,
Mr Danny Rogers, waterbird specialist.

2.4 Pilot studies and method refinement

Stage 1 – Review of Proposed Method (Hardie et al, 2006)

The approach undertaken by Hardie et al (2006) for the development of the draft Estuary FLOWS method was comprehensive and included reviews of the international estuary research and knowledge and Australian and international methods for determining estuarine freshwater requirements. These reviews were used as the basis for the development of a preliminary draft method for the determination of environmental water requirements for estuaries.

This preliminary draft method was evaluated in a discussion paper which summarised the:

- various types of estuaries
- applicability of a single method to determine water requirements
- sensitivity of estuaries to flow alteration including critical flow components that influence their functionality
- knowledge base regarding the role of freshwater flow components in maintaining or enhancing environmental assets and the ecological function of estuaries
- identification of research requirements and data gaps for determining catchment sourced water requirements for Victoria’s estuaries

This discussion paper was the basis of a workshop of several environmental flow scientists and managers who debated the issues in the discussion paper and all aspects of the preliminary draft method. The feedback received during the workshop and subsequent internal reviews led to the refinement of the draft method which was to be trialled in Victoria.

The resulting document (Hardie et al 2006) was formally and externally reviewed by Professor Angela Arthington and Dr Bill Peirson which highlighted issues to be addressed in the pilot applications of the method.
Stage 2 – Field Trial and Refinement

The draft methodology by Hardie et al (2006) was piloted on two Victorian estuaries. The choice of the two estuaries was based on three biophysical criteria and one logistical criteria. The biophysical criteria included:

- Data richness
- Estuary type
- Geographical location

It was believed that the extent and quality of data available would have a bearing on the costs, and timeliness of trials. Data rich sites will require less data collection and as a consequence could be undertaken at a lower cost and within a shorter timeframe than sites with limited and or poor data. Data rich sites have an additional benefit in the trialling and refining the method. While trialling the method on a data poor estuary would assist to quantifying and confirming data collection costs, the disbenefits greatly outweigh this benefit.

Secondly, it was thought that estuary type may affect how the method was applied due to significantly different physical attributes. It was recommended that the method be trialled on an estuary with a permanently open mouth and a second estuary with an intermittently open mouth.

Thirdly, it was thought that trialling the method on estuaries in geographically different regions would be beneficial. Principally this would assist the capture of information and test the applicability of the method based on any geographic differences such as the distribution of fish, birds or vegetation.

Finally, the one logistical criteria was to ensure adequate support and that appropriate institutional partners could be involved and support the implementation and refinement of the method.

Consideration of all these factors lead to the draft methodology being piloted in two estuaries: the Gellibrand River estuary and the Werribee River, and these pilot applications were used to refine the methodology.

The draft methodology paper was reviewed by Professor Angela Arthington and Dr Bill Peirson before the method was finalised and presented in this report.
3 VICTORIAN WATER ALLOCATION POLICY AND PRACTICE

3.1 Legislation

In Victoria all water is owned by the Crown. The Water Act 1989 provides the mechanism by which the Minister for Water may issue entitlements to authorities and delegate the function of issuing entitlements and licences to individuals for the take and use of water from Victoria’s waterways and aquifers. The Water Act 1989 establishes the availability of water for the environment and water for consumptive purposes. Water for the environment is known as the Environmental Water Reserve.

The Environmental Water Reserve can be held in storage (regulated rivers), as run-of-river flows (unregulated rivers) also known as rules based water, or as a groundwater level.

3.2 Planning

a) Water allocation planning

The balance between water available in the Environmental Water Reserve and water available for consumptive purposes is managed through a number of planning and regulatory mechanisms.

Across Victoria, allocation ‘caps’ are in place for all waterways to ensure that water for new development is sourced either through water trading or through ‘winter- July to October’ diversions. The allocation of water during this period is guided by the Sustainable Diversion Limits. No new entitlements or licences can be issued for the taking of water during the ‘summer- August- June’ period.

In addition to the ‘caps’ water diversions are managed through rules applied to licences and water entitlements. Bulk water entitlements, which are those provided to authorities for the purposes of supplying urban or rural water users stipulate ‘passing flows’ below storages and weirs, restrictions and maximum volumes to be harvested. Licences are held by individuals and relate to ‘unregulated’ rivers i.e. those not regulated through the control of flows by large reservoirs or weirs. Licences stipulate restriction and cease to divert levels in order to protect the share of water available for the environment.

Where a catchment is over allocated, water recovery can take place in priority rivers. Water recovery can be achieved through two key planning processes:

- Stream flow management plans- for localised planning in unregulated rivers
- Sustainable water strategies- for regional scale planning

These planning processes can result in amendments to bulk water entitlements and licences and establishment of environmental water entitlements. Environmental water entitlements are the most secure source of water for the Environmental Water Reserve.

In order to undertake water recovery, information is needed on the environmental water requirements of the river, and estuary, along with information on the water requirements of the consumptive users. The FLOWs method, along with EEFAM, will provide the data required to develop a program of improvement to the Environmental Water Reserve for a particular river or estuary.

b) River health planning

The Victorian River Health Strategy (VRHS) provides the strategic framework for river health management in Victoria (NRE 2002a). The VRHS provides a Vision for Victoria’s rivers and
provides the basis from which priorities for protection and restoration can be set. The VRHS will be reviewed in 2010, and will incorporate the strategic framework for river, wetland and estuary management in Victoria. The new Victorian Strategy for Healthy River, Estuaries and Wetlands (VSHREW) will also incorporate themes of resilience and adapting to climate change.

A key component of the VRHS and VSHREW is the direction to develop regional strategies for healthy rivers, estuaries and wetlands. Regional River Health Strategies, developed by catchment management authorities, provide medium and long term condition targets for specific rivers, estuaries and wetlands along with shorter term (five year) action targets. Values and condition targets identified through these strategies can form the basis from which objectives in EEFAM and FLOWs are set.

### 3.3 Environmental water reserve planning tools

#### a) Sustainable diversion limits

In 2002 the Department of Natural Resources and Environment developed recommendations for Sustainable Diversion Limits over winter fill periods in unregulated Victorian catchments. The Sustainable Diversion Limits (SDLs) was an initiative to establish operational rules for water sharing among users, including the environment. SDL are a conservative estimate of the maximum extraction from a stream system beyond which there is an unacceptable risk that significant impacts on the environment are likely to occur. SDL’s have been developed for streams across Victoria, largely based on hydrologic criteria and historical data. SDLs are a top down approach.

Recommendations for estimating the SDL are based on a:

- Winter fill period over which diversions can occur
- Minimum flow threshold below which diversions should cease
- Maximum daily rate
- Annual licensed volume associated with a specified reliability of supply.

The volume of water that can be sustainably diverted from a catchment depends on both climatic factors, as well as the physical attributes of each individual catchment.

SDLs are conservative to ensure a high degree of protection to the environment. In some situations where there is a demand for additional water resources development, detailed site specific FLOWs and EEFAM studies can be used to assess the availability of the resource beyond the SDL.

#### b) FLOWs method

In 2002, the FLOWS method (NRE 2002b) was developed as a standard approach to undertaking environmental flow studies on Victorian Rivers. FLOWs identifies the environmental flow regime required for a healthy stream. A FLOWs project for a river system identifies a range of flow components which are specifically devised to meet ecological objectives. FLOWs involves the mixing of ecological, hydrological and hydraulic information to determine a flow regime which can be used in water allocation processes. Since 2002, FLOWs has undergone a number of refinements and has been used extensively in Victoria and used in Tasmania, South
Australia and Western Australia. It has been the basis from which water has been recovered to add to the environmental water reserve.

FLOWS studies are independent technical studies undertaken by scientific experts, which are one component in the water allocation decision making process.

c) Environmental flows for Victorian estuaries

FLOWS has been applied to many coastal streams, however the environmental flow requirements of the estuaries were not explicitly studied or recommended. Therefore there was a gap, for estuaries, if further development was to be undertaken on coastal streams. Victoria’s estuaries are areas of significant biodiversity and high social value and it was essential that flows were considered as one component of keeping them healthy.

In 2006, Doeg and Pope undertook an analysis of the ‘The adequacy of using ‘Sustainable Diversion Limits’ as a filter for determining further environmental water studies in Victoria’s estuaries. This project concluded that ‘Diversions at or below the SDL guidelines therefore represent a reasonably low threat to downstream estuarine processes during the high flow period for which it is applicable.’

For water recovery purposes, or for consideration of the impacts of water resource harvesting beyond the limits set by the SDL, EEFAM will be used in priority estuaries.
4 EEFAM COMPONENTS AND CONCEPTS

4.1 Preamble

This section describes the concepts and components of the method which need to be taken into consideration in applying the full EEFAM method to estuaries in Victoria. It explains the basis for the method and provides some of the rationale behind the inclusion of the steps that constitute the method. The next section describes the actual method and outlines the steps required to undertake an estuary environmental flow assessment.

4.2 EEFAM Objectives

The primary objective of EEFAM is to define the flow regime which must be provided to maintain ecological health of an estuary.

A healthy estuary may change over time and the assessment of estuarine health as part of the EEFAM should consider past changes, possible future trajectories of the estuary including targets for health set in the regional river health strategy.

The flow regime comprises the elements of river hydrology which are significant to ecosystem health and which can be defined or measured hydrologically.

Riverine inflows influence the physical environment of the ecosystem in terms of water chemistry, stratification and mixing, water level and habitat structure/diversity, temperature and exchange with the marine environment. Riverine inflows also influence geomorphological features such as sand bars, channel structure and the opening and closing of the estuary’s entrance. Changes to river hydrology can alter the prevailing physical environment in the estuary with implications for flora and fauna habitat requirements such as cues for migration, life history processes and recruitment of plants and animals. (Figure 1).

Estuarine Health

The EEFAM adopts the Victorian River Health Strategy (VRHS) definition of a healthy river (or estuary) as one which retains the major ecological features and functioning of that estuary prior to European settlement and which would be able to sustain these characteristics into the future. A healthy estuary need not be pristine. There may be exotic species present. In some areas along the estuary, the fringing vegetation zone may be significantly reduced. Some areas of the associated wetlands may be disconnected from the estuary. It is an estuary where some aspects of condition may have been traded off to provide for human use of freshwater inflows. However, overall, the major natural features, biodiversity and/or functions of the estuary are still present and will continue into the future. However, an Index of Estuary Condition is under development (for DSE by Deakin University) which is being designed to assess the “naturalness” or “health” of estuaries and which defines the naturalness of an estuary by its biological communities.
The role of EEFAM is to build a recommended inflow hydrology, or flow regime, from the known dependencies of geomorphological features, physical limnology and flora and fauna on flow.

The role of riverine inflows is determined principally from the application of existing knowledge to the estuary. Objectives are set for specific ecological and geomorphological outcomes for a given level of estuarine health and the flow components required to achieve them are identified. Together, these flow components represent a recommended flow regime (Figure 2).

The bottom up (or building block) approach (cf. King and Louw 1998) was taken because it conforms with the asset based approach of the Victorian River Health Strategy. This requires that assets are identified and measures put in place to protect them. It has the additional advantages of fitting in with FLOWS, it can be applied simultaneously, and conforming to the initial estuaries method study (Hardie et al. 2006). The EEFAM framework seeks to maintain essential ecological functions but does not seek to protect the full range of ecological processes and production and biomass.
Many of the habitat requirements of flora and fauna to which riverine inflows contribute are also influenced by marine and local estuarine processes. Management of riverine inflows is clearly only part of a suite of processes needed to protect ecological health. Where other processes are important they are identified in EEFAM and, where possible, recommendations are made for their provision and management. However, these are incidental considerations. The primary objective of EEFAM is to address estuary requirements for riverine inflow.

4.3 Estuary Definition (Study Area)

The area of interest for EEFAM is from the estuary entrance to the upstream limit of the estuary; defined here as the upper limit of measurable tidal variation. This definition has been adopted as it the basis that the Department of Sustainability and Environment adopted to identify and map Victoria’s estuaries (Barton et al, 2008). Upstream of this point, the FLOWS method can be used to describe environmental water requirements. Upstream of the tidal influence, the stream is essentially a linear feature where a single input variable, discharge, can be used to predict depth, velocity and area of inundation using a one-dimensional hydraulic model, of the river and its floodplain, as specified by FLOWS.

Where tides influence water levels, one-dimensional hydraulic models are no longer sufficient to describe the relationship between discharge and water level. EEFAM sets out the more complex tools required to predict these relationships and to describe associated salinity structures (e.g. haloclines) and the effects of estuary closure.

Riverine discharge influences the marine environment by modifying salinities, nutrient levels, sedimentary processes and providing cues for migration and other animal behaviours. Consideration of the marine environment is within the scope for EEFAM insofar as important offshore physical attributes and ecological values can be directly related to water management in the estuary. In general EEFAM only sets objectives for upstream of the estuary entrance.

The lateral boundary of the study area is the extent of inundation at the highest known water level in the estuary.

4.4 Flow Components

The objective of EEFAM is to recommend the flow regime required to achieve estuary health. This goal is based on the assumption that biological or physical outcomes can be related to a suite of specific hydrological events. EEFAM applies this assumption by describing the hydrology of the main discharging watercourse as comprising a set of ‘flow components’. The hydrological conditions required for ecological processes (such as fish migration or spawning) or physical processes (such as sediment movement) to occur can be defined by the characteristics of one or more flow components.

Flow components are typical flow events in the main discharging watercourse. They are defined in terms of:

- Discharge (the magnitude required)
- Timing (when, seasonal pattern, etc)
- Frequency (how often)
- Duration of flows (how long they last)
- Rate of change in flows (how fast or how slow, hydrograph shape)

The hydrograph of any stream can be described in terms of these components (Richter et al. 1997). The unique hydrological character of streams is defined by the timing, frequency and
duration of events of particular and magnitude within this broad framework. The magnitude, timing, frequency, duration and rate of change of flow may be identified for any one of a number of flow components that make up the hydrologic regime. Figure 3 graphically represents the riverine flow components that may occur over a period of time.

The flow components in the estuaries method include:

- Cease to flow periods (1)
- Summer low flow periods (2)
- Freshes (3)
- High Flow periods (4)
- Bankfull events (5)
- Overbank flood events (6)

The following non-freshwater aspects of estuary flow regime include:

- tidal fluctuation;
- storm surge;
- dynamic entrance conditions (variable downstream hydraulic boundary condition);
- dynamic salinity profile

These components are considered in the hydraulic modelling and outputs will inform the panel on how ecological objectives can be met by each component.

Figure 3. Examples of freshwater inflow components that may be delivered to an estuary over a period of time (from Hardie et al 2006).
Cease to Flow

Inflows to estuaries cease in some catchments, particularly in summer and autumn when rainfall events in the catchment are less frequent. Cease to flow can be an important characteristic of estuaries as it will result in the upstream movement of the salt wedge and overall salinisation of the estuary.

Low Flow

The hydrology of estuary inflows is generally analysed in two seasons, a low flow period in summer and autumn and a high flow period in winter and spring.

Low flows are derived from intermittent rainfall events in the catchment and persistent groundwater contributions. They vary little from day to day and are either perennial or at least a series of prolonged events. Low flows are best described on a monthly basis.

Low flows control the upstream movement of the salt wedge and can be important in maintaining a freshwater environment in the upstream part of the estuary. Low flows can therefore contribute to the diversity of estuaries by maintaining habitat for freshwater fish and vegetation throughout the year.

Low flows may contribute to elevated water levels at high tide.

Low Flow Freshes

Peaks in flow during the low flow period are termed low flow freshes. These result from individual runoff events (a storm or series of storms) which cause estuary inflows to rise for a number of days. Hydrological descriptions of freshes are normally event based: for a particular flow threshold, the frequency and duration of events in the low flow period is given.

Low flow freshes can be large enough to temporarily drive the salt wedge closer to the estuary entrance. Water levels may be elevated, possibly introducing water to vegetation communities on the estuary banks or floodplain during the summer/autumn period.

Low flow freshes can provide important cues to fish for spawning or upstream migration. For example, this flow component will allow migration of Australian Grayling juveniles from an estuary to freshwater reaches and allows migration of Common Jollytails to the estuary in autumn before spring tides.

Substantial freshes in the low flow period can maintain the estuary entrance by transporting sand which would otherwise restrict marine exchange or completely block the mouth. Summer-autumn periods with a blocked entrance can be subject to anoxia, stratification and elevated water levels for prolonged periods. Environmental flows studies should review the frequency of flows of the required magnitude to open the entrance.

High Flows

High flows are defined hydrologically as the period of the year with elevated baseflows (winter and spring). Estuary inflows occur reliably throughout this period and are normally described on a monthly basis or as a flow occurring for a certain percentage of the high flow period.

High flows influence the extent of the salt wedge and mixing in the estuary. High flows are therefore important to water quality. High flows also influence water level and can contribute to higher levels at high-tide. High flows may have insufficient energy to open a closed estuary entrance, but they will contribute to the maintenance of estuary entrances that are prone to
blockage. More than one high flow threshold may be specified. Higher discharges will generally occur for less of the winter-spring period.

**High Flow Freshes**

Peaks in flow in the high flow period are termed high flow freshes. These result from rainfall events in the catchment and tend to be larger and occur more frequently than freshes in the low flow period. Hydrologically, high flow freshes are described as events which have a specific peak discharge that can be described with a particular frequency and duration.

High flow freshes control many ecological processes in winter and spring. They export sediment from the estuary entrance and can be important to maintaining exchange with the marine environment. They can drive marine water completely from the estuary. High flow freshes can have sufficient energy to mobilise bottom sediment, which can remove silt and sand from seagrass beds. Freshes provide important cues to fish to migrate to or from the estuary.

Water levels may be raised by high flow freshes to inundate riparian or floodplain habitat independently of tidal levels. Floodplains can require inundation to maintain vegetation, provide flooded, vegetated habitat for fish and waterbirds and to fill wetlands.

Different sized freshes will have different ecological and geomorphological outcomes. They will also occur with different frequencies and durations.

**Bankfull and Overbank Flows**

Very large flows which reach the bankfull level (as defined by a Geomorphologist) or go over the bank and create widespread flooding are events which are not necessarily seasonally based. They are be created by unusually high rainfall periods which can occur at any time of year. Geomorphological outcomes are not seasonally based and relate to channel and floodplain shape and form through the mobilisation and transport of sediment.

Estuaries may depend on bankfull and overbank flows to sustain floodplain processes. The distinction between these flows and high flow freshes is a question of hydrological judgement based on seasonality, frequency and hydraulics.
4.5 EEFAM Project Team

EEFAM involves three key groups, the Steering Committee (SC) which commissions and guides the project, the Estuary Environmental Flows Technical Panel (EEFTP) which undertakes the work and a Community Consultative Committee where information is exchanged with the community. These groups are coordinated by Project Managers (PM) which administers the project from the point of view of the client and the project team.

Steering Committee and Client Project Manager

The Steering Committee comprises natural resource managers and agency staff with a responsibility for the ecological health and management of water in the estuary. This will most likely involve representatives from DSE (Sustainable Water and Environment Division), the Catchment Management Authority, water corporation and other agencies. The Steering Committee makes the key strategic decisions in the project including:

- development of the project objectives
- approval of the project scope
- the selection of the EEFTP
- review and approval of EEFTP reports against the EEFAM methodology and project objectives

![Figure 4 Project governance for EEFAM studies](image)
The Steering Committee is represented in the day-to-day implementation of the project by the Client Project Manager. The Client Project Manager is responsible for briefing the EEFTP and coordinating the resources required to undertake the project. These include the provision of existing data, access to local knowledge and access to the estuary. The Client Project Manager gives direction to the EEFTP and monitors project deadlines and deliverables. Project management groups and roles are shown in Table 1 and Figure 4.

**Table 1 Project governance and roles**

<table>
<thead>
<tr>
<th>Role</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steering Committee</td>
<td>- Project oversight</td>
</tr>
<tr>
<td></td>
<td>- Selection and appointment of EEFTP and Community Consultative Committee</td>
</tr>
<tr>
<td></td>
<td>- Provision of data</td>
</tr>
<tr>
<td></td>
<td>- Access to experts in their agency</td>
</tr>
<tr>
<td>Client Project Manager</td>
<td>- Day-to-day management of project</td>
</tr>
<tr>
<td></td>
<td>- Liaise with Panel Project manager and EEFTP</td>
</tr>
<tr>
<td></td>
<td>- Coordinate the resources required to undertake the project</td>
</tr>
<tr>
<td></td>
<td>- Ensure information, such as existing data, access to local knowledge and access to the estuary, is provided to EEFTP</td>
</tr>
<tr>
<td>Community Consultative Committee</td>
<td>- Inputs on vision and values of estuary</td>
</tr>
<tr>
<td></td>
<td>- Provision of access to local knowledge and access to the estuary</td>
</tr>
<tr>
<td>Panel Project Manager</td>
<td>- Day-to-day management of project and EEFTP</td>
</tr>
<tr>
<td></td>
<td>- Co-ordination of field inspections and panel workshops</td>
</tr>
<tr>
<td></td>
<td>- Co-ordination of reporting</td>
</tr>
<tr>
<td>Estuary Environmental Flows Technical Panel</td>
<td>- Provision of expertise throughout the project</td>
</tr>
<tr>
<td></td>
<td>- Involved in all key decisions and recommendations</td>
</tr>
</tbody>
</table>

**Estuary Environmental Flows Technical Panel**

EEFAM is implemented by an expert panel of which one member is the Project Manager.

Members of the EEFTP provide expertise throughout the project and all key decisions and recommendations are made by the EEFTP jointly. This integration ensures that a range of disciplines are involved in the outcomes.

The panel should comprise specialists in the following disciplines:

- **hydrology** to characterise estuary inflows and statistically describe the hydrological characteristics of ecologically and geomorphologically significant events;

- **hydraulic modelling** to develop and interrogate a hydrodynamic model which relates estuary inflows, tide level, and estuary entrance opening to salinity, salt wedge dynamics, water velocity and level;
physical estuarine limnology (oceanography) to characterise processes relating to water quality, biogeochemistry, microbiology, salt wedge dynamics, sediment/water column processes, stratification and estuary opening;

freshwater and marine plant ecology to set ecological objectives and to recommend flows to achieve them;

fish and macroinvertebrate ecology to set ecological objectives and to recommend flows to achieve them

gEomorphology to set objectives for geomorphological processes and to recommend flows to achieve them

waterbird ecology to set objectives for waterbirds and to recommend flows to achieve them.

Members of the EEFTP must have experience in applying their expertise to the assessment of environmental water requirements within estuarine systems.

Groundwater often has an important role in the hydrology and salinity of estuaries. The discharge of groundwater to an estuary can greatly modify soil moisture and salinity regimes such that floodplain plant communities and aquatic fauna habitat cannot be adequately explained in terms of the surface water regime alone. Groundwater expertise may be required in the panel if there is sufficient local groundwater monitoring data to develop meaningful, semi-quantitative predictions about interactions between groundwater and estuary salinity and hydrology. If not, groundwater contributions to the study may be limited to the identification of future data requirements or a conceptual understanding of the processes.

The EEFTP Project Manager will be responsible for the coordination of the EEFTP, communications with the Client Project Manager and the delivery of the project outcomes. The EEFTP Project Manager must ensure that data and other resources required by the EEFTP are requested from the client. The Project Manager is responsible for delivery of project outcomes according to the agreed scope and time frame.

Community Consultative Committee

Establishing good communication with stakeholders, including the community of the estuary, has been highlighted as one of the foundations of good governance in estuaries (Gippel et al. 2008).

A consultative committee of community, industry and cultural stakeholders should be convened. The committee has three roles: to provide the EEFTP with information which will support their investigations, to consider and contribute to the objectives developed by the EEFTP and to inform the wider community of the investigation processes and outcomes.

The consultative committee can bring important local knowledge to the project such as records of flora, fauna, hydraulics (water level, flood extent, flow paths), water quality and estuary management. Much of this information will be associated with major historical events such as floods and is more useful if it can be linked with specific dates. Photographs of the estuary at various flood stages or degrees of entrance closure can be helpful in calibration of a hydrodynamic model.

4.6 Asset-Based Approach

EEFAM makes recommendations on the flow requirements of multiple ecological and geomorphological assets. This contrasts with early approaches which are less complex and rely upon one element such as fish habitat. Holistic methods like EEFAM and DRIFT (Downstream

In EEFAM, assets are the plant species, plant communities, fish species, bird species or other faunal assemblages dependent upon the estuary which will be used in the evaluation of water requirements. The recommended flow regime for the estuary comprises the amalgamated flow requirements of these assets. The recommended flow regime is built up from hydrology and hydraulics at transects agreed upon by all experts as representative of particular flow-biophysical relationships along a river, and each expert attempts to relate their component to all underlying biophysical components. Flow requirements are amalgamated through a workshop where conflicting and complementary flow requirements are identified and resolved as necessary.

Flow recommendations must indicate the conservation values of the estuary. It is therefore important that assets are chosen that respond to a wide range of flow events and estuary mouth opening and salinity states. Risk of inadequate flow recommendations is reduced when a wide range of assets is chosen with responses to the widest range of flow events and estuary states (mouth opening status).

Assets must also be selected with regard to available data. Environmental flow methods which use the building-block approach (King and Louw 1998), such as EEFAM, assume that all of the important roles of flow in terms of the habitat and ecological requirements of assets can be identified and quantified. It relies heavily on the availability of detailed autecological data or on defensible scientific opinion. This aspect of EEFAM is founded on conceptual models which must be based on cited scientific literature or other documented information sources. The lack of well established information can be a risk to the approach or rather its outcomes but no more so than most other e-flow methods. There is an argument that careful selection of a range of assets on which flow requirements are based can provide checks and balances not provided in less complex methods.

In selecting the assets, the conservation values of the estuary must be considered. Assets represent aspects of the river which hold value for the community and about which the community would be concerned if they were lost or degraded or where there are legislative imperatives to protect them. Environmental values, which are usually identified through regional river health strategies, will include:

- the presence of rare or threatened species and/or communities;
- species listed or protected by Victorian or Commonwealth government legislation;
- significant geomorphological features associated with the river;
- sites of significance e.g. Ramsar wetlands; and
- areas with high levels of naturalness of components of the ecosystem.

In summary, a comprehensive set of assets must be selected to encompass the freshwater inflow requirements of all estuary flora and fauna. An important review task in EEFAM is to determine whether the flow requirements of species of conservation or management significance are adequately represented by the selected assets.

4.7 Conceptual Models

The role of flow in directly providing for the habitat and other requirements of ecological assets and in driving ecological, geomorphological and salinity processes (which indirectly provide for
some habitat and life history needs) will be defined in conceptual models. The models will be applied to estuaries to set ecological and environmental flow objectives as part of the methodology set out in Chapter 5.

The models will be maintained in a central library and will be transferable between estuaries. They will bring to each estuary the accumulated knowledge of previous EEFAM studies and will bring a consistent and appropriate approach to the determination of hydrological objectives. Each model will have a universal component, which documents scientific knowledge that is believed to be generally applicable, and a local component which is applicable to the estuary in question.

A high degree of scientific expertise is required to adapt and apply the models to individual estuaries. They are not off-the-shelf components of EEFAM but require expert opinion to be interpreted and applied so as to incorporate local ecological and physical data. It is expected that each EEFAM study will amend and improve each model used with new scientific knowledge.

The library of conceptual models will be maintained by a central agency. The library will comprise models for the environmental water requirements of fish, birds and vegetation and models that link flows with ecologically relevant geomorphological and salinity processes. Only models validated by the EEFTP and the SC at the end of a project should be included in the library.

Each EEFAM study will draw on the library for models which are relevant to their estuary. Models will be adapted to account for local conditions or to incorporate new information. Improvements may originate from local monitoring data, the scientific literature or expert opinion. Where studies identify revisions or improvements which may be applicable to other estuaries, they must be added to the library. All data must be fully cited to allow future users to assess its relevance, accuracy and applicability.

EEFAM studies will develop new models for previously undescribed ecological assets for which flow recommendations are required. New models will have the same format as existing models and must comply with minimum standards (see below). New models must be added to the library at the completion of the study so that they may be applied elsewhere.

The conceptual model library will:

- establish a satisfactory, minimum standard for the ecological basis to set flow recommendations;
- enable continuous improvement in EEFAM studies;
- reduce effort by sharing accumulated knowledge; and
- provide consistency to facilitate the review of EEFAM studies.

**Minimum Standards - Vegetation**

It is expected that vegetation conceptual models will be based on Ecological Vegetation Classes (EVCs). EVCs are mapped throughout Victoria and provide a consistent vegetation classification unit which can be associated with a single flooding, salinity and groundwater environment. Plant community structure and important component species are identified. The relevant components of the physical environment are described such as topographic setting, surface water regime (salinity and level), groundwater regime (level and salinity), wave exposure, geomorphological processes and soil type. The tolerable limits and optima of flow-dependent physical conditions will be described in terms of depth, salinity, temperature, residence time and any other flow-
mediated physical parameter. Limits and optima will be determined from the scientific literature, local monitoring data and knowledge and expert opinion. They may be reported for the community as a whole or for plant species within the community. The source of limits and optima must be cited.

A schematic diagram illustrating the role of flow in the habitat and ecological requirements of the vegetation will be prepared using Adobe Illustrator and the IAN symbol libraries from the University of Maryland’s Center for Environmental Science (see http://ian.umces.edu/). An example of a conceptual model for Estuarine Reedbed is provided in Figure 5.
Representative Objective – Estuarine Reedbed (EVC 952)

Estuarine Reedbed has a ‘rare’ conservation status in the Warrnambool Plains bioregion.

Estuarine Reedbed occupies extensive areas of the floodplain approximately 1 to 3 km from the estuary entrance. It lies above the level of the daily high tide and is flooded only when estuary levels are particularly high (Arundel, 2006). This may result from closure of the entrance, unusually high tides, flood flows or a combination of these factors. Estuarine Reedbed occurs in freely draining areas which do not retain water when estuary levels recede. Flooding events will usually last several days to weeks and will be separated by periods of several days to weeks.

Flood water will tend to be brackish or fresh. The lower salinities reported from backwater ponds (Table 3) range between 2,700 and 17,000 EC and indicate salinities during general floodplain inundation. The floodplain is underlain by shallow groundwater which will have a lower and less variable salinity. It is likely that groundwater sustains the growth of deep-rooted aquatic macrophytes in the Estuarine Reedbed.

Estuarine Reedbed is dominated by *Phragmites australis* which forms dense and sometimes impenetrable beds. *Phragmites australis* tends to be most dense, tallest and particularly dominant on local rises on the floodplain such as the levees along the river bank. This species is favoured by inundation from late winter to late summer, reaching maximum canopy biomass in mid-late summer, although it responds to floods at other times (Hocking 1989a, 1989b).

Conditions become suboptimal within 1 km of the estuary entrance where surface water and groundwater salinities are likely to be higher. In this area *Juncus kraussii* is the dominant species and occurs with *Schoenoplectus pungens*, *Poa poiformis*, *Baumea juncea* and *Triglochin striata* (Breen 1982).

Conditions are also suboptimal for *Phragmites australis* in deeper floodplain areas within the Estuarine Reedbed. This may be because the depth of flooding is too great or because there is potential for water to pool and become too saline for *P. australis* through evaporation. These areas support a diverse community which includes the graminoids *Juncus kraussii*, *Isolepis nodosa* and *Poa poiformis* and a herb layer of *Cotula coronopifolia*, *C. reptans*, *Triglochin striata*, *Suaeda australis*, *Selliera radicans* and *Samolus reptans* (Breen 1982). *Sarcocornia quinqueflora* can also be present (pers. obs. M. Cooling). When subject to regular or sustained flooding, presumably in spring, Estuarine Reedbed can include *Chara* sp., *Nitella* sp., and *Ruppia maritima*. Areas flooded with fresher water can include *Rumex bidens*, *Calystegia sepium* and *Lotus hispidus* (Breen 1982). Ecological and hydrological requirements are shown in Figure C.

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**Plant assemblages:**

A On rises and higher ground in the floodplain, inundated by winter freshes - *Phragmites australis*

B On lower points in the floodplain, inundated to a greater depth by winter freshes and subject to evaporative concentrations of salts from estuary water - diverse community including: *Juncus kraussii*, *Isolepis nodosa*, *Poa poiformis*, *Cotula spp.*, *Triglochin striata*, *Suaeda australis*, *Sarcocornia quinqueflora*.

C At the edge of the main estuary channel *Juncus kraussii*, is present beneath and adjacent to *Phragmites*.

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**Figure 5 Example conceptual model for Estuarine Reedbed EVC**
**Minimum Standards - Fish**

Conceptual models will be developed for representative fish species to be considered in environmental flow determinations. The models will describe the major life-cycle stages which interact with estuary flows such as spawning, recruitment, migration and dispersal. The habitat components used by the fish at each of these stages will be identified. The role of flow in providing tolerable or optimal conditions in each habitat will be described for each component. The consequences of sub-optimal conditions, such as fish kills, failure to spawn or failure to migrate will be described. The basis used to describe habitat and ecological requirements and optimal habitat conditions must be cited.

A schematic diagram illustrating the role of flow in the habitat and ecological requirements of the fish will be prepared using Adobe Illustrator and the IAN symbol libraries. An example of a conceptual model for the Common Jollytail (*Galaxias maculatus*) is provided in Figure 6.

**Minimum Standards – Birds**

Conceptual models of birds species or guilds will be required when their habitat requirements contribute to specific environmental flow recommendations. Similar to fish, the models must describe the life-cycle stages which are influenced by estuary flows such as breeding, nesting and sourcing food. The habitat components used by the birds at each stage must be identified. The role of flow in providing tolerable or optimal habitat will be described for each habitat component. The consequences of sub-optimal conditions, such as failure to breed or local extinction, will be described. The basis to describe habitat components and optimal habitat conditions must be cited.

A schematic diagram illustrating the role of flow in the habitat and ecological requirements of the birds will be prepared using Adobe Illustrator and the IAN symbol libraries.

**Minimum Standards – Geomorphology**

Conceptual/deterministic models will be developed for describing the processes of sediment entrainment, transport and deposition. Where possible, these models should be grounded on known physical laws, so that modellers can apply the functions to make numerical predictions. Where possible, the uncertainty concerning the predictive power of the relationships should be stated. All relationships need to be described in detail, including source of original equation, units, and applicable realm. Conceptual models will be required linking the deterministic sediment dynamics models to ecologically important processes.

A schematic diagram illustrating the role of flow in geomorphological processes will be prepared using Adobe Illustrator and the IAN symbol libraries.

**Minimum Standards – Salinity Dynamics**

Conceptual/deterministic models will be developed for describing the processes of salinity distribution within estuaries. These models should be grounded on known physical/chemical laws, so that modellers can apply the functions to make numerical predictions. Where possible, the uncertainty concerning the predictive power of the relationships should be stated. All relationships need to be described in detail, including source of original equation, units, and applicable realm. Conceptual models will be required linking the deterministic salinity dynamics models to ecologically important processes.

A schematic diagram illustrating the role of flow in salinity processes will be prepared using Adobe Illustrator and the IAN symbol libraries.
Representative Objective – Common Jollytail (*Galaxias maculatus*) - Estuarine Dependent (Freshwater Derived)

Common Jollytails are a widespread and often abundant species in Australia found in coastal lakes and streams at low altitudes from Adelaide in the west to Southern Queensland in the east (McDowall and Fulton 1996). They are also present in New Zealand and South America having a Gondwanian distribution. They are a significant species in the ecosystem as a food source for other fish and birds and are a significant invertebrate predator (Koehn and O'Connor 1990; McDowall 1996; Merrick and Schmida 1984). Ecological and hydrological requirements are shown in Figure B.

**Habitat**

Common jollytails are able to utilise a wide range of habitats and have a preference for still or slow moving waters. They are capable of withstanding freshwater to very high salinities (well above that of sea water.) They are known to also occur in landlocked populations (Koehn and O'Connor 1990; McDowall 1996; Merrick and Schmida 1984).

**Movement**

In autumn adults move downstream to the estuary to spawn on a full or new moon and a high spring tide. The eggs hatch and the small, slender larvae are washed out to sea. The juveniles spend winter at sea and return to freshwater about 5 to 6 months later (Treadwell and Hardwick 2003; McDowall and Fulton 1996).

**Reproduction**

Common jollytails spawn amongst vegetation (grasses, samphire and other low vegetation) around river estuaries when under water at high tide. Most adults die after spawning. The eggs remain out of water for two weeks or more until the next spring tides, the eggs hatch on being re-inundated and the larvae migrate (or are washed out) to sea (McDowall and Fulton 1996). Eggs can tolerate and hatch in salinities ranging from fresh to seawater (Cadwallader and Backhouse 1983).

**Information for conceptual model for common Jollytail**

- Provide flows to allow longitudinal connection in the channel for adult jollytail movement down to the estuary in January to March
- Provide flows to open mouth to allow downstream migration of larvae in autumn
- Provide flows to open mouth to allow juveniles to migrate upstream from sea between July and December
- Provide flow freshes to inundate vegetation beds and instream benches to stimulate invertebrate production for fish condition

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**Figure 6 Example conceptual model for *Galaxias maculatus***
4.8 Translating Habitat Requirements to Hydrological and Hydraulic Thresholds

EEFAM relies on the translation of the physical, flow-dependent habitat and ecological requirements described in the conceptual models into the hydrological events and hydraulic processes which can be evaluated by the hydraulic model and hydrological analysis.

Thresholds must be identified which represent the point at which the habitat requirements are first provided. Example thresholds are presented in Table 2. When the thresholds are known, the mechanism to provide them can be determined and the frequency, duration and timing of events required to achieve them can be determined.

Table 2. Examples of hydrological and hydraulic thresholds

<table>
<thead>
<tr>
<th>Habitat Condition</th>
<th>Threshold</th>
<th>Investigation Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular removal of silt from seagrass beds</td>
<td>Bed shear stress</td>
<td>Hydrodynamic model</td>
</tr>
<tr>
<td>Migration of fish from estuary to marine environment</td>
<td>Discharge to achieve minimum entrance dimensions</td>
<td>Hydrology: flow which achieves required entrance dimensions</td>
</tr>
<tr>
<td>Flooding of floodplain wetlands in spring</td>
<td>Estuary water level</td>
<td>Hydrodynamic model to determine estuary level at high tide</td>
</tr>
<tr>
<td>Availability of saline water in estuary</td>
<td>Position of halocline</td>
<td>Hydrodynamic model to determine halocline position and shape at various flows.</td>
</tr>
</tbody>
</table>

Cooperation within the EEFTP is critical to this part of the EEFAM process. The physical scientists require the ecologists to define habitat requirements in terms which can be tested by hydrological and modelled hydraulic data. The ecologists require the physical scientists to explain flow events and hydraulic processes in terms which are meaningful to habitat structure, diversity, spatial pattern and timing of occurrence.

The Peirson et al, 2002, processes provide a framework to identify and describe the linkages between habitat condition and flow components. The processes list major physical and ecological processes and their sensitivity to inflow reductions (Peirson et al. 2002). The processes describe the role of flow in determining physical conditions in the estuary, such as temperature, depth, dissolved oxygen and sediment transport. The significance of these features to estuarine flora and fauna is identified (see Figure 7 for an example).
Figure 7 The role of Peirson et al (2002) processes in linking habitat condition to hydraulic and hydrological thresholds

The Peirson Processes must be evaluated for their applicability to an estuary in each EEFAM study. The evaluation of the processes and their applicability to a particular estuary forms a type of risk assessment and is an important tool in the EEFAM to highlight the critical processes to be preserved or avoided.

Peirson et al. (2002) processes describe sixteen major physical and ecological processes (Table 3) that represent ecological responses to various flow components. These sixteen processes were adapted from Bishop (1999), and are grouped by magnitude. These groups (abbreviated and presented below) include low fresh water inflows, moderate to high fresh water inflows and several that relate to all inflow magnitudes. Subsequent to Peirson et al. (2002), Peirson (pers. comm.) has added an additional three flow dependent estuary processes.
Table 3 Major ecological processes by which reduced estuary flows can impact on estuarine ecosystems (Peirson et al, 2002; Processes Low 9-11 were added by Peirson pers. comm. in Hardie et al 2006)

<table>
<thead>
<tr>
<th>Flow Component</th>
<th>Process</th>
<th>Nature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>No. 1</td>
<td>Increased incidence of hostile water quality conditions at depth</td>
</tr>
<tr>
<td></td>
<td>No. 2</td>
<td>Extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive fauna</td>
</tr>
<tr>
<td></td>
<td>No. 3</td>
<td>Extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive flora</td>
</tr>
<tr>
<td></td>
<td>No. 4</td>
<td>Extended durations of elevated salinity in the lower estuary allowing the invasion of marine biota</td>
</tr>
<tr>
<td></td>
<td>No. 5</td>
<td>Extended periods when flow-induced currents cannot suspend eggs or larvae</td>
</tr>
<tr>
<td></td>
<td>No. 6</td>
<td>Extended periods when flow-induced currents cannot transport eggs or larvae</td>
</tr>
<tr>
<td></td>
<td>No. 7</td>
<td>Aggravation of pollution problems</td>
</tr>
<tr>
<td></td>
<td>No. 8</td>
<td>Reduced longitudinal connectivity with upstream river systems</td>
</tr>
<tr>
<td></td>
<td>No. 9</td>
<td>Increased retention times in estuary reaches</td>
</tr>
<tr>
<td></td>
<td>No. 10</td>
<td>Nutrient influxes from density dependent saline surface water - shallow groundwater interactions</td>
</tr>
<tr>
<td></td>
<td>No. 11</td>
<td>Reduced longitudinal connectivity with the downstream marine environment (Mouth Opening connectivity with marine environment) (Low Flow and High Flow)</td>
</tr>
<tr>
<td>Middle-High</td>
<td>No. 9</td>
<td>Diminished frequency of flushing of the estuary bed of fine sediments and organic matter – reducing the quality of physical habitat</td>
</tr>
<tr>
<td></td>
<td>No. 10</td>
<td>Diminished frequency of flushing of organic matter from deep sections of the estuary – reducing water quality</td>
</tr>
<tr>
<td></td>
<td>No. 11</td>
<td>Reduced channel maintenance processes</td>
</tr>
<tr>
<td></td>
<td>No. 12</td>
<td>Reduced inputs of nutrients and organic material</td>
</tr>
<tr>
<td></td>
<td>No. 13</td>
<td>Reduced lateral connectivity and reduced maintenance of ecological processes in water bodies adjacent to the estuary</td>
</tr>
<tr>
<td>All</td>
<td>No. 14</td>
<td>Altered variability in salinity structure</td>
</tr>
<tr>
<td></td>
<td>No. 15</td>
<td>Dissipated salinity/chemical gradients used for animal navigation and transport</td>
</tr>
<tr>
<td></td>
<td>No. 16</td>
<td>Decreases in the availability of critical physical habitat features, particularly those components associated with higher velocities</td>
</tr>
</tbody>
</table>
4.9 Hydrological Analysis and Hydrodynamic Modelling

The occurrence of flow-dependent habitat conditions is evaluated using hydrological analysis and hydraulic modelling.

Hydrological analysis occurs in two phases. The first phase occurs in the early stages of the project with the purpose of characterising the basic hydrology of the system in order to inform the Technical Panel. This analysis provides basic statistics on monthly freshwater inflow distribution, monthly net evaporation distribution, flood event distributions, spells of potential mouth closing events (if a threshold can be defined), and spells of potential salt wedge flushing events (if a threshold can be defined). If tide data are available then these data should be analysed using statistics that are meaningful to ecologists. For example, standard harmonic analysis may be less useful than simpler descriptive statistics of tidal range distributed by months or seasons.

The second phase of hydrological analysis occurs after the flow objectives and flow components have been defined, and the hydrodynamic characteristics of the estuary are understood. The distribution of each flow component is defined using statistics that are appropriate for the component. Baseflow is defined as water that enters a stream or river from persistent, slowly varying sources, maintaining streamflow between rainfall events, which contrasts with water that enters a stream or river rapidly, called stormflow, quickflow or event flow. For events, the frequency, duration and inter-annual variability will need to be characterised for the natural series and the current series (and future series if such a scenario is being considered). For baseflow components (Low Flows and High Flows), characterisation of the monthly distribution (and including a measure of dispersion) will be required. If hydraulic thresholds cannot be defined for baseflow components, the Technical Panel may utilise a hydrological index.

If this is the case, then it is advised to first separate baseflow from quickflow using a recursive digital filter, such as described by Lyne and Hollick (1979), and then characterize the baseflow using descriptive statistics for each month or season.

The second phase of hydrological analysis also includes calculation of compliance. Compliance is the degree to which the specified flow components occur in the flow series. A compliance statistic is a way of comparing the relative performance of flow scenarios, and it allows the Panel to reality check their expectations regarding required frequency and duration of their defined flow components. The recommended method of compliance analysis is described in Gippel et al. (2009).

Two hydraulic models are required.

A **simple, 1 dimensional Flood Model** (such as HEC-RAS) is used to determine the flows required to achieve a range of water levels on the floodplains of estuaries.

A **complex, 2-dimensional vertical slice Tide Model** (RMA or equivalent) is used to describe the estuary at sub-bankfull flows. The model describes the movement of water and the salt profile in response to riverine inflow, tide and exchange at the estuary entrance.

The complexity of hydraulic modelling is constrained in EEFAM. Hydrodynamic models of estuaries can be developed to a high degree of sophistication but require funds, time and input data beyond the scope of a standard methodology. Certain compromises have been made to balance the accuracy and reliability of model outputs with available time and resources expected in a standard methodology which can be applied to all Victorian estuaries (For full details and justification see Appendix C).
4.10 Minimum Data Requirements

Before an EEFAM study is commissioned, a 30 year record of daily modelled flow is required. If the study is to compare inflow scenarios, such as current, natural, future development or climate change scenarios, then modelled flows for these must also be available.

It is expected that relevant existing data will be provided including any records of the following:

- estuary entrance behaviour, including the history of any natural and artificial openings
- salinity and dissolved oxygen structure at various flow states
- estuary water quality
- Air photos of the site and events
- photographs depicting flood extent on particular dates (these may be available from community members)
- water level gauging
- survey benchmarks

Hold points are provided in the method to allow for the scoping and collection of the minimum data requirements. This will increase timelines significantly if extensive data collection is required.

4.11 Assumptions and Limitations of the Method

This project methodology is repeatable and scientifically defensible within the budget and timeframes proposed. The results will be robust, provided:

- minimum data requirements are met;
- timeframes will allow for seasonal data to be collected and time for workshops and iterations between the professionals involved in the project; and,
- the conceptual understanding of the hydrology, geomorphology, and ecology of the system is well known, and habitat and ecological requirements of the system’s key assets can be linked to freshwater flow events.
- modelling calibrations are appropriate.
- the estuary environmental flows technical panel must be of an appropriate level of knowledge and expertise.
5 EEFAM SPECIFICATION

The EEFAM specification is made up of 9 steps described in the Figure 8 below:

**Figure 8 Flow chart of EEFAM steps**
5.1 Step 1. Project Establishment

The project will be directed by a steering committee comprising representatives of agencies responsible for managing water and environmental values in the estuary.

The steering committee will determine the required outcomes of an estuary study and how they will be addressed by EEFAM. The pre-existing data requirements must be reviewed to ensure that they will be available at the commencement of the project. The minimum data requirements must be met or delays in project delivery will be unavoidable. The project scope will be prepared and comprise Steps 2 to 9 of EEFAM as set out below. It will also:

- briefly describe the physical and environmental setting of the estuary
- identify key management and community stakeholders in estuary management
- identify known environmental values
- identify known threats to environmental values, and whether they are thought to be flow-related
- specify the required outcomes of the project
- specify the project time frame and reporting stages
- list data sources available to support the study
- provide project data and reports to the EEFTP.

The Client Project Manager will accordingly prepare a brief to engage the EEFTP.

The Steering Committee will select the EEFTP and hold an initiation meeting with the Project Manager to review the scope of work, how it will be addressed by the EEFTP, potential difficulties and complexities in the project, relevant stakeholder interests and timelines for completion.

The Client Project Manager will collate existing data relevant to the project for provision to the EEFTP at the initiation meeting.

The first Community Consultative Committee meeting will be held in the establishment phase of the project. The Client Project Manager will explain the objectives and scope of the project and the activities and time frames involved. The Project Manager will explain the methodology and the roles of the project team members. The community representatives will explain their interest, knowledge and concerns for the estuary. It is possible that the community may provide resources helpful to the hydrological, hydraulic and ecological characterisation such as species lists, fish catch records, water level records or photos at various flood or tide levels. Community members should be made aware of the value of these records and procedures established to provide them to the project. It is required that both an ecologist and physical scientist from the EEFTP attend this meeting. It is important for the committee members to appreciate the time frames involved and the limitations of the project.

Outputs:

- Meeting Notes
  - Information list
  - Values documented
5.2 Step 2. Characterisation of Physical Estuary Environment

EEFTP will commence a characterisation of the estuary as the first major task of the project. Six months is allocated to this task which will provide the foundation of the environmental appraisal later in the study. This stage will provide a hydrodynamic model and hydrological characterisation of the estuary. It depends on data which must be collected over a period of approximately 3 months and subsequent model development and analysis. This process is represented in Figure 9.

Figure 9 Flow chart for the development and use of hydrological analysis and hydraulic modelling
Step 2A – Hydrodynamic Modelling

EEFAM uses a RMA 2DV or equivalent to model tidal fluctuations in the estuary channel and HEC-RAS (or similar) software to model freshwater flood events. Both models draw on the statistics provided by the hydrological characterisation (Figure 9).

The characterisation will begin with a meeting between the Client Project Manager and the EEFTP hydrologist and hydraulic modeller. Relevant existing data will be provided including any records of the following:

- estuary entrance behaviour, including the history of any natural and artificial openings
- salinity and dissolved oxygen structure at various flow states
- estuary water quality
- photographs depicting flood extent on particular dates (these may be available from community members)
- water level gauging
- survey benchmarks

The estuary will be inspected by the EEFTP project manager and others as required (if necessary by boat) in order to prepare the scope of the characterisation. The members of the EEFTP best suited to attend the initial inspection is likely to be the hydraulic modeller and an ecologist as this inspection leads to surveys, data collection and the site paper. Inspection will allow description of the nature and scale of important physical controls on water movement. These will include the estuary entrance, the floodplain, constrictions in the channel, sand bars, reefs or sills and channels. Vertical profiles of temperature, salinity and dissolved oxygen should be collected at 4 – 6 sites along the estuary during this initial site visit.

The location and orientation of survey cross-sections will be selected (using inputs from both ecological and physical scientists).

A simple longitudinal bathymetric profile is required for the hydraulic models. The use of a depth sounder on this inspection may be sufficient to collect this data. In large or complex estuaries the longitudinal profile may need to be determined professionally.

A surveyor will be engaged to collect the required cross-sectional data. The brief will be prepared according to the specifications in Appendix C. A draft of the brief will be provided to the Client Project Manager to incorporate any additional requirements of the client. A surveyor will be engaged to collect the data.

In addition, a field program will be developed to collect the following data:

- automatic water level gauging at sites within the estuary and outside the estuary over a period of at least 30 days (ideally 60 days)
- salinity, temperature and dissolved oxygen measurements at four to six locations at a range of depths over a period of two days (this is for model calibration only, further field trips or previous data will be required for understanding the dynamics of the system)
- continuous stream discharge gauging while the tide gauges are deployed (30 to 60 days)

A detailed specification for these investigations is provided in Appendix C.
The survey data will be used to develop the one-dimensional hydraulic Flood Model. The model will also draw on calibrated channel roughness estimates developed from the Tide Model (see below). The objectives of the Flood Model are to:

- quantify the bankfull capacity of the estuary channel and
- approximate flood levels through the estuary and support the interpretation of ecological processes

A detailed specification for the flood model is provided in Appendix C.

When the flood model and field program is complete, a two dimensional vertical slice Tide Model will be developed using RMA-10 or an equivalent hydrodynamic software package (Appendix C)

The Tide Model will be used to provide a series of standard scenarios which represent a preliminary sensitivity analysis of estuary tidal dynamics and salinity structure to different inflow discharges (Figure 10). The model should be run to demonstrate estuary sensitivity to:

- two entrance area conditions (closed, open or intermediate as appropriate)
- constant and flushing inflows
  - four 'constant low' inflow conditions (from low summer baseflow to high winter baseflow)
  - three freshwater 'flushing' flows (80%, 100% and 120% bankfull discharge)
- downstream boundary: using a repeating spring-neap tidal cycle.

The parameter specifications above define 8 basic model runs (2 x entrance area, 4 x constant inflow) and 6 additional runs that commence at the endpoint of a subset of basic runs. The simulations can be divided into two stages which demonstrate:

- saline recovery and low flow characteristics; and
- flow required to flush the estuary of salt.
Figure 10 Simulation schedule for tide model

The following outputs are required from the sensitivity analysis.

- animation of the longitudinal salinity profile (under various scenarios)
- snapshot of the salinity structure (1 each on the ebb and flood tide – see Figure 11)
- time series variation of vertical salinity profiles (top, middle and 2nd from bottom layers at 4 to 5 discrete locations along the estuary)
- variation in velocity (top, middle and 2nd from bottom layers) at 4 to 5 discrete locations along the estuary.
- saline recovery
- residence time

The hydrodynamic model should be used to report the response of the salinity profile to high flow events and to explore the flows required to flush the estuary. Scenarios are recommended for 80%, 100% and 120% of the bankfull discharge with flow held at this level for 1 to 2 weeks. The flushing flow analysis would provide:

- an animation of the longitudinal salinity profile; and
- salinity time series extracted from near the estuary entrance for each scenario.

A detailed specification for these investigations is provided in Appendix C.
Figure 11 Salinity distributions at four times through the tidal cycle with 100 ML/day

Step 2B – Hydrological Characterisation

The purpose of the initial hydrological characterisation is to summarise the daily flow data so that the EEFTP can gain a conceptualisation of the basic hydrological type of estuary under investigation, and the range of event magnitudes, frequencies and durations typical of the estuary (i.e. scope out the basic character of inflows, their relative size, and distribution through time). At this stage it is not possible to characterise the frequency and duration of events of particular magnitude, because the EEFTP has not yet decided on what these magnitudes (i.e. of flow components) should be. Detailed characterisation of individual flow components comes later, and is part of compliance testing of the recommended flow components (i.e. to see how the specified flow components are distributed in the flow scenarios).

The basic analysis will include:

- Estimation of net evapotranspiration from the estuary, on a monthly basis, and then comparison of this with monthly inflows to the estuary. This analysis indicates if and when the estuary is in a negative hydrological balance (i.e. evaporative losses exceed inflows, and the estuary water level is likely to fall over time, or the estuary will draw in water from any connected water body, whether that is fresh or saline). The spells of events of negative hydrological balance should be characterised.

- Monthly flow distributions of selected flow indices. These can be selected by the hydrologist to suit the requirements of the ecologists, but median flow, flow exceeded 5% of the time (high flow index) and flow exceeded 95% of the time (low flow index) are good basic statistics. Other statistics may be requested by the hydrodynamic modeller. The objective is to provide a characterisation of flow seasonality, and some idea of typical flow magnitudes for the system under investigation. If data are available for flow scenarios, then comparing results for the scenarios will provide the EEFTP with a good idea of the degree of deviation from the benchmark case (normally the modelled natural flow series).
Flood series analysis. This is traditional annual series of partial duration series analysis, using peak instantaneous flow data if available (not available for REALM modelled flows). Distributions should be fitted to the series, rather than using eye fitted curves or interpolation. The objective is to provide a characterisation of the magnitude of flow events that occur over a range of average recurrence intervals.

For any pre-defined important hydrological events (i.e. already determined for the estuary in question, and described in the literature) undertake spells analysis to describe the distribution of these events (including mouth closure and opening spells).

If baseflow components are defined on the basis of hydrological (as opposed to hydraulic) thresholds, undertake baseflow separation using a numerical filter, and establish rules for defining periods of time when flows are "dominantly baseflow" and "dominantly quick flow". The rule might be based on certain threshold values for the baseflow index (ratio of baseflow to quickflow). The detail of how this should be done is not prescribed here; it is up to the hydrologist to apply an appropriate methodology.

**Step 2B – Groundwater Characterisation**

If groundwater investigations are included in EEFAM, field work to collect basic data on groundwater should be undertaken at this stage. The scope of groundwater investigations should be limited to the characterisation of aquifers which directly influence the salinity or soil moisture environment of environmental assets. In most cases, this will be require the manual installation and monitoring of shallow piezometers in the floodplain. The installation of deeper monitoring bores, which would clarify aquifer interactions and regional groundwater gradients, will generally be outside the scope of an EEFAM study.

Piezometers should be sited to sample lateral and vertical gradients in hydrostatic head and salinity. This will generally require nested piezometers at the edge of the floodplain and at the edge of the estuary channel at one or more location. The piezometers should be included in the physical survey. This will allow piezometer levels to be related to estuary surface water levels and to existing monitoring bores and will allow simple interpretation of local lateral groundwater gradients.

If piezometers are installed at the commencement of the physical characterisation, it may be possible to get two or even three quarterly salinity and depth measurements to describe seasonal groundwater variation.

In general, these investigations should be designed to clarify whether groundwater has a freshening or salinising effect on floodplain and riparian habitat and whether groundwater contributes to soil moisture. If these aspects of groundwater are not understood, surface water may be assigned functions in the EEFAM process which it does not provide. The quantification of these processes would require a groundwater model which is outside the scope of EEFAM.

The groundwater report will draw on existing reports and data as well as data collected in the field program. It will provide a description of regional aquifers interacting with the estuary and regional and local hydrostratigraphy. Vertical and lateral gradients in level and salinity must be described. The processes driving ecologically important groundwater dependent features such as springs, soaks, soil salinity and seasonal patterns must be interpreted. Outputs from this step will be:

- hydrodynamic model
Environmental flow recommendations assume that groundwater extractions remain the same as at the time of the assessment of flow requirements – therefore any additional extraction is assumed to have an impact on the estuary’s ecology.

5.3 Step 3. Site Paper

Step 3A – Establish Policy Context for Objectives

The flow recommendations made by EEFAM are founded firmly in the established environmental policy for estuaries. Flow recommendations represent the practical application of national, state and regional policies for ecosystem and water management. It is important that the EEFAM report sets out the policy foundation of flow recommendations, which may be challenged due to conflicts with other natural resource interests.

Key documents, policies, strategies and plans which would be useful for setting the strategic context to every EEFAM study are listed in Appendix B.

These policies should be reviewed and only be presented in the Issues Paper insofar as they guide environmental water management. Regional and local policies will be more specific and potentially more relevant. For example, Ecological Character Descriptions for Ramsar Sites specify the environment which must be provided to maintain the wetlands.

Step 3B – Ecological and Geomorphological Characterisation

The objective of this stage is to provide the setting for environmental flow recommendations by characterising the geomorphological and ecological environment and conservation priorities. This background discussion must provide the overall context and collate the data required to develop the conceptual models in the Issues Paper.

This stage will characterise flow-dependent ecological and geomorphic assets, features and processes in the estuary. In general, EEFAM projects will only be commissioned when there is sufficient data to complete the project, so this characterisation will usually be detailed and comprehensive.

Geomorphology

The geomorphology of the estuary is characterised in terms of the estuary type (see Dalrymple et al., 1992; Boyd, et al., 1992 and http://www.ozcoasts.org.au/conceptual_mods/index.jsp), the boundaries of the estuary geomorphic zones (see Barton, 2003 and http://www.ozcoasts.org.au/conceptual_mods/index.jsp), sites of established local, regional, state, national or international geomorphological significance (if present) (White et al., 2003, and for information on the local area see http://new.dpi.vic.gov.au/vro), history of geomorphological change and threats, estuary flushing and mouth closing dynamics, and sediment transport dynamics (incoming loads and deposition rates).
The characterisation is to be undertaken using quantitative methods wherever possible. For example, sediment loads are to be calculated using sediment concentration and discharge data (if data are available), also making reference to the NLWRA (National Land and Water Resources Audit) predictions for the river (see http://www.anra.gov.au/topics/soils/erosion/index.html, and access the predictions for river links from the Australian Natural Resources Data Library at http://adl.brs.gov.au/anrdl/php/basic_search.php). Geomorphological change can be accessed through aerial photography or on-ground survey comparison (if data are available). The Geomorphologist then sets the geomorphological objectives on the basis of: (i) the review and analysis of data, and (ii) consultation with other Technical Panel members regarding the geomorphological processes and forms that have known links to ecological health.

Vegetation

The Site Paper must describe the vegetation communities and significant species in the estuary in the context of the catchment and the bioregion. The vegetation characterisation will account for floodplain, riparian, wetland and aquatic communities.

Within the estuary, the location, composition and condition of plant communities is to be described with respect to controlling environmental factors. Vegetation is to be described on the basis of available EVC and other vegetation mapping, field observations and local vegetation surveys.

The conservation significance of estuarine species and communities at a local, state and national level is to be reported. Species of management concern to the community must also be specified.

Fish

The fish fauna is important to estuary health as a source of food for birds, humans and other organisms and some species are also of conservation and economic significance. Fish interact with a wide variety of habitats in the estuary and respond to a wide variety of flow-related cues such as river discharge, velocity, temperature, salinity and water levels. Analysis of fish habitat and ecological requirements therefore provides an extensive and comprehensive set of ecologically-meaningful physical criteria to assess ecosystem health. Specifying fish requirements for flow makes it possible to identify management measures with a high conservation return.

The fish fauna of the estuary should be characterised by a review of available records of fish from the estuary. This includes data from the Atlas of Victorian Wildlife, records from local naturalists and scientific research. The habitat requirements of fish are reviewed to identify the behaviours and habitat and life history requirements of fish in the estuary. It is often useful to categorise the fish fauna into functional groups based on how the fish use the estuary. Previous classifications have identified, estuarine residents; estuarine dependent; and estuarine opportunists as three main groups, Figure 12 (Hindell pers. comm. and Arundel 2006.). This classification is helpful in identifying the key habitat components of the estuary and their importance to fish life-stages. These included requirements for passage through the estuary entrance and access to seagrass meadows, floodplain vegetation and freshwater reaches of the catchment. They also included specific flow events such as freshes, tide levels and halocline dynamics.

A subset of fish species should be selected to define flow requirements for fish. The species are selected to:
represent a wide variety of habitat requirements which were sensitive to flow and water management in the estuary;

represent each of the functional groups (Estuarine Residents, Estuarine Dependents, Estuarine Opportunists);

include species for which there was a significant autecological knowledge-base; and

include species of conservation (listed under Flora and Fauna Guarantee or Environment Protection and Biodiversity Conservation Acts) or management (fisheries valued species) significance or as specified by local management plans, Victorian bioregional and state wide frameworks, Commonwealth legislation and local community stakeholders.

Figure 12 Functional fish groups present within estuaries in Victoria (Hindell pers. comm. and Arundel 2006)

For the selected species ecological information should be collated on all aspects of life history which interact with flow. This includes requirements for breeding, spawning, juvenile development, dispersal, migration, predation, shelter and resting. Information will be sought on the physical habitat conditions at each stage. Physical habitat conditions include simple water quality parameters such as temperature, dissolved oxygen and salinity and complex water quality parameters such as halocline development and stratification. Habitat requirements also include access to specific habitats within the estuary, such as passage through the estuary entrance, access to the floodplain and access to upstream riverine reaches.

Birds (if included)

Birds may be included in EEFAM if there are good reasons to expect that waterbird habitat requirements will lead to more specific flow recommendations than that of vegetation and fish. In general, waterbirds depend on the physical habitat provided by vegetation and surface
water and the habitat requirements of fish and vegetation will also address the requirements of birds. Most bird species are mobile and opportunistic and will readily disperse to other sites when conditions in the estuary are unfavourable. It is difficult to set local habitat objectives for birds when the consequences of inadequate habitat can only be interpreted in a regional context.

Bird fauna are most likely to have a role in EEFAM where:

- there are local resident populations which will be measurably impacted by an inappropriate flow regime;
- the estuary predictably provides habitat features which will have measurable impacts on local or regional waterbird populations if they are no provided.

A characterisation of waterbirds will involve a review of the bird fauna and the range of flow-dependent habitat components on which they depend. The characterisation should provide detail on the species of management significance, describing where they occur in the estuary and their conservation significance.

If the bird fauna does not meet these criteria, the importance of vegetation, geomorphological or fish objectives to waterbirds should be emphasised in the other characterisations above.

**Groundwater (if included)**

Groundwater may be included in EEFAM if there are good reasons to expect that the groundwater environment is sensitive to the estuary inflow regime and that an inappropriate regime will have ecological impacts within the estuary. Estuaries typically have close interactions with groundwater because they are located in groundwater discharge zones and groundwater levels and salinity are influenced by estuary salinity and water levels.

The site paper will provide a summary of the groundwater studies in area, what is the distribution of groundwater bores, whether there is significant extraction of groundwater and usefulness of the available information. This information would be used to decide upon the risks that groundwater extraction may have on the estuary condition and whether additional groundwater studies are required.

It will be unusual to have the network of shallow monitoring bores required to develop local conceptual models of groundwater-estuary water interactions. However, the installation of bores can be inexpensive and it may be possible to collect data prior to the EEFAM study commencing to support groundwater conceptual models.

Groundwater is most likely to have a role in EEFAM where there are unusual groundwater features, such as freshwater discharging to the floodplain. However, the groundwater environment is generally governed overwhelmingly by regional processes rather than local processes at the discharge point.

The characterisation of the groundwater will involve a description of regional aquifers interacting with the estuary and regional and local hydrostratigraphy. Vertical and lateral gradients in level and salinity must be described. The processes driving ecologically important groundwater dependent features such as springs, soaks, soil salinity and seasonal patterns must be interpreted. It is important that these ecological important processes are raised in the first field trip workshop to provide appropriate guidance to the hydrologeologist as the site paper is prepared.
Step 3C - Nominate Conceptual Models

Each characterisation will conclude with the nomination of species, features or processes for which conceptual models (see above) will be developed. The models must be selected to comprehensively represent the role of flow in sustaining the environmental values of the estuary. They must be comprehensive in terms of their spatial representation of the estuary, the flora and fauna that are represented (particularly species of conservation significance), in terms of temporal variability at tidal, seasonal, flow event and annual scales and in terms of flow variation. This comprehensiveness must be demonstrated in the Site Paper.

Outputs:

- site paper
  - characterisation of estuary
  - identification of features of conservation and management significance
  - features and processes identified for development of conceptual models

5.4 Step 4. EEFTP Site Inspection and Workshop

Panel representatives meet with the Community Consultative Committee to present the scope of the project, to learn of local stakeholder interests and values in the estuary and to gain access to locally-held information.

An inspection will be conducted to introduce the EEFTP to the site and to provide a context for the review of existing information which will follow. The site inspection will best be led by the hydraulic modeller and hydrologist who will be most familiar with the physical setting of the estuary. The inspection must:

- present control features such as reefs, channel constrictions, the estuary entrance;
- demonstrate channel depth and shape;
- illustrate the normal tide and storm levels at a range of distances from the estuary mouth;
- review floodplain and wetland geomorphology;
- inspect physical aquatic fauna habitats such as wetlands, holes, reefs, vegetation;
- describe salt wedge dynamics (shape, depth and extent);
- describe the influence of estuary closure (if relevant) on water levels;
- for a range of flood events describe the depth, duration and extent of inundation on the floodplain;
- present known sediment movement processes;
- view vegetation to allow all EVCs to be mapped and described;
- assess the need for groundwater data;
- discuss the surface water salinity dynamics in the channel and in floodplain depressions.

A workshop is required at the end of the site inspection to draw together the issues initially considered important to the study and to identify key topics and themes for the Issues Paper. Each member of the team is required to describe the flow-dependent features or processes of
management significance and to identify linkages to other disciplines. This will take the form of a preliminary checklist and will allow each team member to see how their component of the study will guide or inform other components. Examples are provided in Table 4 below.

**Table 4 Examples of linkages between ecological and physical issues to be explored in the 'Issues Paper'**

<table>
<thead>
<tr>
<th>Component</th>
<th>Key Issues</th>
<th>Linkages</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation</td>
<td>Floodplain depressions must be filled periodically to maintain aquatic vegetation</td>
<td>- refer to cross sections to specify locations and elevations</td>
<td>Plant Ecologist</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- geomorphological processes supporting floodplain depressions to be investigated</td>
<td>Geomorphologist</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- hydrodynamics of floodplain inundation to be reported</td>
<td>Hydrodynamicist</td>
</tr>
<tr>
<td></td>
<td>Zostera beds require periodic removal of sediment</td>
<td>- Zostera sediment tolerances to be specified</td>
<td>Plant Ecologist</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- sediment transport to be characterised</td>
<td>Geomorphologist</td>
</tr>
<tr>
<td>Fish</td>
<td>Salt wedge position critical to Black Bream breeding</td>
<td>- salt wedge dynamics must be characterised</td>
<td>Fish Ecologist</td>
</tr>
<tr>
<td></td>
<td>Freshes provide key triggers</td>
<td>- freshes allow fish movement upstream or out of estuary</td>
<td>Fish Ecologist</td>
</tr>
</tbody>
</table>

There will be significant savings in time and effort if many of these linkages are identified before the EEFTP begins writing the Issues Paper. It is possible that knowledge gaps will be identified at this stage, particularly the need for additional cross sectional data. The workshop should conclude with a plan to address these issues. It is anticipated that most estuaries can be explored in less than 1 day, with a one hour workshop held at the end of the day.

**Outputs:**

- Site conditions observed at first hand by EEFTP leading to:
  - Understanding of site’s ecology, physical conditions and processes of the estuary;
  - Identify need for additional data, transects, etc

**5.5 Step 5. Issues Paper**

An Issues Paper should be prepared which will establish the hydrological, geomorphological and ecological objectives for the study. Conceptual models will be prepared for each of the species, communities or assemblages (assets) nominated in the Site Paper. The conceptual models will describe the role of the estuary water regime in model function. They will identify
key outcomes which will become the ecological, geomorphological and salinity objectives for the estuary.

Relevant models will be drawn from the conceptual model library and additional models developed as required. Models must be adapted to local conditions such as known tolerances to salinity, flow regime, turbidity or other physical parameters. The models must be populated with sufficient local quantitative detail to allow measurable hydrological and hydraulic thresholds to be identified, such as elevation and position within the estuary. The thresholds define the successful provision of the modelled flow requirements.

Ecological objectives are established for the critical flow-dependent aspects of the environmental assets. Objectives must be selected to represent normal, steady state conditions as well as intermittent events. Steady state requirements may relate to the position of the salt wedge in the estuary for fish habitat. Intermittent events may relate to inundation of the floodplain, opening of the estuary mouth, export of deoxygenated water or freshes which trigger fish migration and breeding.

Peirson et al, 2002, processes are available to help link the ecological and physical objectives of the models to the driving hydrological and hydrodynamic processes.

The geomorphology of the estuary is characterised in terms of the estuary type, the boundaries of the estuary geomorphological zones, sites of established National, State or regional geomorphological significance (if present), history of geomorphological change and threats, estuary flushing and mouth closing dynamics, and sediment transport dynamics (incoming loads and deposition rates). The geomorphologist then sets the geomorphological objectives on the basis of: (i) the review of data, and (ii) consultation with other Technical Panel members regarding the geomorphological processes and forms that have known links to ecological health.

For each flow event, the required timing, frequency and duration should be estimated as a hydrological objective. It should be recognised that estimates based only on habitat requirements may not align with the actual flow regime of the estuary. The purpose of these estimates is to assist the hydrologist and hydraulic modeller to report the relevant aspects of estuary behaviour from which flow recommendations can be developed.

The ecologists on the EEFTP would collectively identify critical flow dependent ecological functions, processes or values (Ecological Objectives). Reference to the Peirson et al, 2002, processes should be made to develop a common framework amongst objectives set.

The Issues Paper will be presented to the Steering Committee and the Community Consultative Committee. The presentation must clearly set out the outcomes which the conceptual models support. The presentation by EEFTP Project Manager to the Community Consultative Committee (CCC) and Steering Committee (SC) would allow feedback to be received and would incorporate comments, improvements, and concerns to finalise the Issues paper.

Outputs:

- Issues Paper
- Conceptual Models
- Ecological Objectives
- Hydrological Objectives
5.6 Step 6. Model Interrogation

Each of the conceptual models is presented to the entire EEFTP at an internal workshop. The purpose of the workshop is to ensure that:

- the ecological and hydrological objectives fully represent the range of flow conditions the environmental assets are likely to experience;
- the hydrological objectives are expressed in a clear format which can be readily investigated by the hydrologist and hydraulic modeller;
- the hydrological objectives generally align with the actual hydraulics, salt dynamics and hydrology of the estuary;
- the hydrological objectives of different environmental assets are consolidated to a single objective when ecological objectives are all achieved by the same hydrological events.

Outputs:

- Modelling scenarios prepared
- Hydrological statistics for critical flow thresholds prepared

5.7 Step 7. Scientific Panel Workshop

The Scientific Panel Workshops allows the ecologists to present conceptual models and ecological objectives to EEFTP and Community Consultative Committee. The Workshop provides an opportunity for the Hydrodynamic Modeller to present discharge magnitudes associated with previously defined ecological objectives. The hydrologist calculates the frequency of the flow components, as defined in terms of seasonality, magnitude and duration. Ideally this is presented as a time series of event occurrence. Initially, this is a reality check on the EEFTP’s initial specification on event frequency. If the events as specified by the EEFTP do not occur, or rarely occur in the natural scenario, then the EEFTP needs to re-evaluate their specification of the flow component. The flow recommendation for each component should be expressed in such a way that the natural scenario has 100% compliance (i.e. the component does not necessarily have to occur in every year, but if this is the case, then it needs to be expressed as part of the frequency specification).

During the workshop the scientists would work together to refine the ecological and hydrological objectives and importantly to develop the flow recommendations for each ecological and geomorphological objective.

Following the workshop, the hydraulic modeller will prepare the scenarios to determine the conditions in which critical water requirement thresholds are met. The hydrologist performs the statistical analyses required to report the timing, frequency and duration of flow events of interest.

Outputs:

- Flow recommendations are identified, discussed and documented
- Outputs from hydraulic modelling
5.8 Step 8. Environmental Water Management Recommendations

The estuary environmental water management recommendations are developed from the previous steps by documenting and justifying flow recommendations. The revised objectives are presented based on the physical modelling reality check during the panel workshop. The revised Issues paper will incorporate flow recommendations and justification in hydrological and ecological objectives tables. An example of the environmental water management recommendations from the Gellibrand River pilot study is show in Table 5.

Outputs:
- Revised Issues Paper

5.9 Step 9. Final Report and Presentation to Stakeholders

The final report supersedes reports by collating all previous components into one document. This is presented to a joint meeting SC and CCC. Comments and feedback will be used to finalise the Final Report.

Outputs:
- Final Report
Table 5 Example of EEFAM recommendations for the Gellibrand River estuary

<table>
<thead>
<tr>
<th>Event/Condition</th>
<th>Magnitude (ML/day)</th>
<th>Frequency (events per season)</th>
<th>Duration (days)</th>
<th>Season</th>
<th>Salinity (or Halocline Present?)</th>
<th>Water Column Position (Depth) for Salinity</th>
<th>Location</th>
<th>Mouth Status</th>
<th>Objective ID</th>
<th>Supporting Objective ID</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer-Autumn</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Cease to Flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SYM/AU</td>
<td></td>
<td>XS10</td>
<td>-</td>
<td>7a-c, 8b, 9a</td>
<td>2b, 2e, 2f</td>
</tr>
<tr>
<td>Low Flow</td>
<td>100 ML/day</td>
<td></td>
<td></td>
<td>SYM/AU</td>
<td>Salinity range of 5 to 30</td>
<td>&lt; 1m</td>
<td>XS10</td>
<td>-</td>
<td>10b</td>
<td></td>
</tr>
<tr>
<td>Low Flow Fresh (Fish Migration)</td>
<td>240 ML/day</td>
<td>at least 4</td>
<td>3</td>
<td>SYM/AU</td>
<td>Median salinity between 5 and 10</td>
<td>0.3m - 1m</td>
<td>XS12</td>
<td>-</td>
<td>9f, 10a</td>
<td>1a.1</td>
</tr>
<tr>
<td>Low Flow Fresh (Galaxiid Spawning)</td>
<td>600 ML/day</td>
<td>2</td>
<td>3</td>
<td>Autumn (March – May)</td>
<td>-</td>
<td>XS10</td>
<td>-</td>
<td>10b</td>
<td>3d</td>
<td></td>
</tr>
<tr>
<td><strong>Winter-Spring</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SYM/AU</td>
<td></td>
<td>XS12</td>
<td>-</td>
<td>3d</td>
<td>1a.2, 2c, 2d, 2e, 6c, 9f, 10f</td>
</tr>
<tr>
<td>High Flow Fresh (Estuarine Conditions)</td>
<td>300ML/day</td>
<td>3</td>
<td>11</td>
<td>Winter-Spring</td>
<td>Median salinity between 15 - 35 Salinity</td>
<td>&gt;0.3 - 1m</td>
<td>XS12</td>
<td>-</td>
<td>6a, 9b</td>
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</tr>
<tr>
<td>High Flow Fresh (Seagrass)</td>
<td>900ML/day</td>
<td>4</td>
<td>4</td>
<td>May - July</td>
<td>-</td>
<td>XS12</td>
<td>-</td>
<td>8a, 9c, 9e, 10c, 10e</td>
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<td></td>
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<tr>
<td>High Flow Fresh (Salt Flushing Flows)</td>
<td>1500/500 ML/day</td>
<td>1-2</td>
<td>4 - 6</td>
<td>Winter-Spring</td>
<td>-</td>
<td>0.3 to 0.5m</td>
<td>XS12</td>
<td>Open</td>
<td>8a, 9c, 9e, 10c, 10e</td>
<td></td>
</tr>
<tr>
<td>High Flow Fresh (Phragmites)</td>
<td>1800 ML/day</td>
<td>7-8</td>
<td>3</td>
<td>Winter-Spring</td>
<td>-</td>
<td>0.25 to 0.5m</td>
<td>XS10</td>
<td>Open</td>
<td>Closed (4 days)</td>
<td>1c, 1d</td>
</tr>
<tr>
<td></td>
<td>200 ML/day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Event/Condition</td>
<td>Magnitude (ML/day)</td>
<td>Frequency (events per season)</td>
<td>Duration (days)</td>
<td>Season</td>
<td>Salinity (or Halocline Present?)</td>
<td>Water Column Position (Depth) for Salinity</td>
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<td>Objective ID</td>
<td>Supporting Objective ID</td>
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</tr>
<tr>
<td>High Flow Fresh (Gahnia)</td>
<td>3900 ML/day</td>
<td>4</td>
<td>2</td>
<td>Any month</td>
<td>-</td>
<td>-</td>
<td>XS 9</td>
<td>Open</td>
<td>3c</td>
<td></td>
</tr>
<tr>
<td></td>
<td>200 ML/day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Closed (12 days)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate Overbank</td>
<td>7000 ML/day</td>
<td>1</td>
<td>1</td>
<td>Any month</td>
<td>-</td>
<td>-</td>
<td>XS 2 &amp; XS10</td>
<td>Open</td>
<td>5b</td>
<td>4c</td>
</tr>
</tbody>
</table>
6 REFERENCES


NRE. 2002b. The FLOWS Method – a method for determining environmental water requirements in Victoria. Report prepared by Sinclair Knight Merz, the Cooperative Research Centre for Freshwater Ecology, Freshwater Ecology (NRE) and Lloyd Environmental Consultants. (Melbourne, Department of Natural Resources and Environment).


1 APPENDICES

A. Information Sources for Estuary Flows Studies

The sources of data to assist EEFAM will include:
- Relevant management plans and strategies
- EEMSS and local estuary mouth opening data and plans
- Victorian Data Warehouse
- Index of Stream Condition Database
- Environment Protection Authority Water Information Management System
- Atlas of Victorian Wildlife
- EVC mapping
- Flora Information System
- management agencies
- the Community Consultative Committee
- local residents
- natural history interest groups

Data sourcing and collation should not be limited to the data sources listed above. These are key sources relevant to all Victorian estuaries and they should be regarded as a minimum level of data coverage.
B. Key documents, policies, strategies and plans which would be useful for setting the strategic context to every estuary FLOWS study Information

| National:                                      |                                                                                           |
|                                               | National Principles for the Provision of Water for Ecosystem (1996)                          |
|                                               | Environmental Protection of Biodiversity and Conservation (EPBC) Act (1999)                  |
|                                               | Waters of Victoria: State Environmental Protection Policy (EPA 2003)                        |
|                                               | State Environment Protection Policy (Groundwaters of Victoria) (1997)                       |
|                                               | Management of Victorias Ramsar wetlands (2002)                                             |
|                                               | Management strategy for marine parks and marine sanctuaries (2002)                         |
|                                               | Victorian coastal strategy (2002)                                                         |
|                                               | Indigenous partnership strategy (2001)                                                     |
|                                               | Coastal Spaces project (2006)                                                             |
|                                               | Catchment Condition report (2001)                                                         |
|                                               | Boating Coastal Action Plan (2005)                                                        |
| Regional/Local:                               | Regional Catchment Strategies                                                              |
|                                               | Coastal Action Plans                                                                      |
|                                               | Fisheries Management Plans                                                                 |
|                                               | Foreshore Management Plans                                                                 |
|                                               | Regional Catchment Investment Plans                                                       |
|                                               | South east Regional Marine Plan                                                            |
|                                               | Estuary Management Plans                                                                   |
|                                               | Site RAMSAR Management Plans and Ecological Character Descriptions                       |
|                                               | Regional River Health Strategy                                                            |
C. **Method for developing the hydrodynamic models required to assess the environmental water requirements of estuaries.**