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Estuary environmental flows assessment methodology for Victoria

March 2012
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<table>
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<th>Abbreviation</th>
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<tr>
<td>CCC</td>
<td>Community Consultative Committee</td>
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<tr>
<td>CMA</td>
<td>Catchment management authority</td>
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<td>DSE</td>
<td>Department of Sustainability and Environment</td>
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<td>EEFTP</td>
<td>Estuary Environmental Flows Technical Panel</td>
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<td>EEFAM</td>
<td>Estuary environmental flows assessment method</td>
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<td>EEFAR</td>
<td>Estuary environmental flows assessment report</td>
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<tr>
<td>EEMSS</td>
<td>Estuary entrance management support system</td>
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<td>EVC</td>
<td>Ecological vegetation class</td>
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<td>EWR</td>
<td>Environmental water reserve</td>
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<td>FLOWS</td>
<td>Victorian statewide method for environmental water requirement determinations in rivers</td>
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<tr>
<td>HEC-RAS</td>
<td>Hydrologic Engineering Center – River Analysis System</td>
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<tr>
<td>IAN</td>
<td>Integration and Application Network, University of Maryland’s Center for Environmental Science (see <a href="http://ian.umces.edu/">http://ian.umces.edu/</a>).</td>
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<tr>
<td>SC</td>
<td>Steering committee</td>
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<tr>
<td>SDL</td>
<td>Sustainable diversion limit</td>
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<td>VRHS</td>
<td>Victorian River Health Strategy</td>
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## Abbreviations

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This report sets out a method to determine the environmental water requirements of estuaries in Victoria. The estuary environmental flows assessment method (EEFAM) is a standard methodology which can be applied consistently across Victorian estuaries.

The primary objective of EEFAM is to define a flow regime to maintain or enhance the ecological health of an estuary. The method is used to inform Victorian water resource planning processes.

The output of EEFAM is a recommended flow regime for estuaries. This recommendation is developed from the known dependence of the estuary’s flora, fauna, biogeochemical and geomorphological features on the flow regime. EEFAM is an evidence-based methodology. This bottom-up or ‘building block’ approach conforms to the asset-based approach of the Victorian River Health Strategy and regional river health strategies.

EEFAM is based on and expands on FLOWS, the Victorian method for determining environmental water requirements in rivers. The list of tasks has been modified and re-ordered in EEFAM to reflect environmental and management issues specific to estuaries. EEFAM and FLOWS can be applied simultaneously to a river and its estuary as part of a whole-of-system approach to environmental flow requirements. Like the FLOWS method, EEFAM is modular, and additional components can be readily incorporated.

The approach undertaken in developing EEFAM was to review existing methods and knowledge for specifying environmental flow requirements of estuaries in Australia and overseas. This produced a draft method, which was trialled and refined by applying it to the Werribee and Gellibrand estuaries.

The final methodology is described in this report and has the following key elements:

- the use of flow components to examine and specify a flow regime
- the use of environmental assets and geomorphologic features to establish environmental objectives
- a clearly documented objective setting process that links environmental objectives to flow objectives and recommendations through the use of ecological conceptual models
- the use of a multi-disciplinary expert panel guided by a steering committee and supported by a community consultative committee
- the specification of minimum data requirements, including field data in order to complete an EEFAM assessment and including an associated hold point
- the use of hydrological tools and hydraulic models to support the development of environmental flow recommendations.
The key requirements for the project were that the method needed to be:

- generally applicable statewide
- completed within 12 months
- scientifically defensible and repeatable
- have a budget around $70,000 per system, not including hydrological data.

The development of the draft method confirmed that the consultancy costs to undertake an EEFAM assessment on a small to intermediate sized estuary were more likely to be $80,000–110,000 (in 2008). Some cases will require application of more complex hydrodynamic models, and will thus have higher costs. Also, in situations where regular tidal variation is less dominant in controlling circulation and water levels, model predictions will be less certain compared to simpler tide-driven cases.

The method as specified in this report will include hydrological, ecological and physical condition assessments of the estuary with a detailed hydraulic model. It requires inputs of base hydrological, water quality and water level data. The higher budget of an EEFAM study compared to a FLOWS study is due largely to the need for a slightly larger panel and more complex modelling.

Implementation of the recommendations are subject to water planning processes. These water planning processes are outside the scope of the method.
The support of the Sustainable Water and Environments Division, DSE and the Corangamite CMA is acknowledged for their funding and project management activities.

An interagency steering committee contributed to the project and ensured its objectives were achieved. Members included:

- Simone Wilkie and Jayden Woolley (Corangamite CMA), Agency Project Managers
- Paulo Lay (Project Manager), Michaela Dommissie 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 Estuary Environmental Flows Technical Panel (EEFTP) consisted of:

- Mr Lance Lloyd (Lloyd Environmental), Estuary FLOWS Project Coordinator; fish and aquatic fauna ecologist
- Dr Brett Anderson (Water Technology), hydrologist and hydraulic modeller
- Dr Marcus Cooling (Ecological Associates), aquatic and floodplain vegetation ecologist
- Dr Chris Gippel (Fluvial Systems), environmental flow and geomorphology specialist
- 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
- Mr Danny Rogers, waterbird specialist.

In addition, the following made special contributions:

- the independent reviewers (Professor Angela Arthington, Griffith University; Dr Bill Peirson, University of NSW; and Professor Gerry Quinn, Deakin University)
- the community consultative committees that supported pilot studies in the Werribee and Gellibrand estuaries.
3. Introduction

Victoria’s limited water resources are subject to competing demands. These demands can often deplete the flow entering estuaries and put the estuaries’ environmental values at risk. To inform the allocation and sharing of water, this estuary environmental flows assessment methodology (EEFAM) has been developed to provide a consistent and systematic approach to determining environmental water requirements for estuaries in Victoria.

3.1 Background and context

In Victoria, ‘FLOWS’ is the accepted method for determining environmental water requirements for the freshwater reaches of rivers. FLOWS is based on the building block methodology (Arthington 1998, Arthington et al. 1998, King and Louw 1998). At present, there is no equivalent accepted method to determine the required input of freshwater flows into estuaries in Victoria.

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

In rivers, discharge is the variable required to predict flow ecology relationships. In contrast, water levels in an estuary are controlled by the complex interaction of freshwater inflow and marine exchange.

Rivers are generally considered to be freshwater systems, whereas salinity is an important flow-dependent variable in estuaries. Distribution of salinity throughout an estuary is dependent on riverine inflow and other variables such as wind velocity and tidal currents. Understanding and modelling salinity structure is important in evaluating estuary water requirements.

Plant communities and faunal assemblages are frequently common across different estuaries in Victoria, to a greater degree than they are in rivers (Cadwallader and Backhouse 1983; McCarraher 1986; Ball and Blake 2009). There is scope to incorporate consistent approaches to determining the water requirements of these communities and assemblages.

River discharge is 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.

The principal differences between FLOWS and EEFAM are that EEFAM requires:
- a modified sequencing of major tasks to enable vital information to be gathered
- a more complex hydrodynamic modelling approach
- an additional workshop to establish hydrological and ecological objectives
- a library of conceptual models for ecosystem water requirements to share data between estuarine studies and improve knowledge.
The purpose of this project was to develop a method for determining the environmental flow requirements to reflect these key differences. The intent was to base the method on the modular approach of the FLOWS method for rivers and adapt and expand it as required for estuaries.

3.2 Project objectives and scope

The initial brief (in 2002) for the draft estuary flows method study was to:
- be generally applicable statewide
- be completed within 12 months
- be scientifically defensible and repeatable
- have a budget around $70,000 per system, not including hydrological data.

The development of the draft method confirmed that the consultancy costs to undertake an EEFAM assessment on a small to intermediate sized estuary were more likely to be $80,000 to $110,000 (in 2008).

Some cases will require the application of more complex hydrodynamic models. These models will have greater data demands and will therefore cost more.

The method as specified in this report (at 2008 investment levels) includes hydrological, ecological and physical condition assessments of the estuary. It requires 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 EEFTP than that required for a FLOWS study, and more complex modelling.

3.3 Project process

The project was developed in a two-stage process which is summarised below.

**Stage 1 – Review of proposed method (Hardie et al. 2006)**

A comprehensive review of existing methods and knowledge for specifying environmental flow requirements of estuaries in Australia and overseas was undertaken by Hardie et al. (2006).

This draft method was evaluated in a discussion paper which summarised the:
- various types of estuaries in Victoria
- applicability of a single method to determine environmental 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.
A group of environmental flow scientists and managers provided feedback on this paper. This feedback and subsequent internal reviews led to a refined draft method.

The draft method (Hardie et al. 2006) was formally and externally reviewed by Professor Angela Arthington (Griffith University) and Dr Bill Peirson who highlighted issues to be addressed in the pilot applications of the method.

**Stage 2 – Field trial and refinement**

The draft method was piloted on two Victorian estuaries (Lloyd et al. 2007a & b; Lloyd et al. 2008a) – those of the Werribee and Gellibrand rivers. The choice of these two estuaries was based on three biophysical criteria:

- the availability of existing data – the extent and quality of data available would have a bearing on the costs and timeliness of trials
- representativeness of the estuary type – estuary type may affect how the method was applied due to significantly different physical attributes
- geographical location – trialling the method on estuaries in geographically different regions would test the applicability of the method based on any geographic differences such as the distribution of fish, birds or vegetation

and one logistical criterion:

- to ensure that appropriate institutional partners could be involved to support the implementation and refinement of the method.

The two pilot applications were reviewed by the Steering Committee, community advisory groups for each site, and external reviewers. The draft method was then refined and updated following the trials (a CD of the flow recommendation reports for these two estuaries is found at Appendix E). The refined methodology report was then reviewed by Professor Angela Arthington, Dr Bill Peirson and Professor Gerry Quinn. The final method is presented in this report.
4. Victorian water allocation policy and practice

4.1 The entitlement framework

a. Rights to Water

Victoria’s water entitlement framework comprises well-defined rights to water, and markets have been established to enable water to be traded between uses. The Victorian Government, under the Water Act 1989, retains the overall right to the use, flow and control of all of Victoria’s surface water and groundwater resources. The Government issues water entitlements to persons or authorities, to allow them to take, store and use water under specific conditions. The water entitlement framework is illustrated in Figure 1.

b. Environmental Water Reserve

In Victoria, the Environmental Water Reserve (EWR) is a legally recognised amount of water set aside to meet environmental needs. It was established in 2005 to provide greater protection for environmental water in our rivers and aquifers (groundwater systems). The objective of the EWR is to preserve environmental values and health of water ecosystems, as well as the beneficial human uses that depend on it.

Water in the EWR is provided in three ways:

- **Environmental water entitlements**: a volume of water held by the environment in perpetuity. In general, they are a share of the available resource (in flows) in storages.

- **Obligations on consumptive entitlements**: the passing flows that water corporations or licensed diverters are obliged to provide out of storage or past a diversion point to protect environmental values.

- **‘Above cap’ water**: the water left over after limits on consumptive use have been reached and unregulated flows cannot be captured in storage. In groundwater systems, the EWR is provided by limiting the volume of groundwater that can be extracted for consumptive use.

For many systems, the environment still retains the majority of total stream flow. The majority of this water available to the environment is ‘above cap’ water (followed by passing flows). Above cap water is a very unreliable source of water for the environment and varies widely from year to year. A significant proportion of above cap water is made up of spills from storages in wet years. In dry years (when storages don’t spill) the EWR is substantially reduced and is therefore particularly vulnerable to the potential impacts of climate change.

In some rivers, one-third to half of natural stream flow is extracted to meet consumptive needs. In some cases, these systems may not have enough water to meet the ecological needs of the river. In these situations, it is often necessary to recover additional water for the environment. Where water recovery has taken place, environmental water entitlements may be created. Entitlements are the most reliable component of the EWR and can be actively managed to meet specific environmental objectives (e.g. delivering water to specific sites at a chosen time by calling water out of storages). Environmental entitlements represent 4% of water available to the environment in Victoria.
Water entitlements are defined in the Water Act 1989 and are issued by the Minister for Water. A water entitlement is the amount of water authorised to be stored, taken and used by a person under specific conditions. Associated entitlements set conditions for water delivery or use.

**Figure 1: Water Entitlement Framework**

- **Water entitlements**
  - Tier 1 - Rights held by Crown
  - Tier 2 - Rights to authorities
    - Environmental water reserve
    - Bulk entitlements
      - Environmental entitlements
      - Obligations on consumptive entitlements
      - 'Above cap' water
  - Tier 3 - Rights granted to individuals
    - Water shares
    - Section 51 licences
    - Section 8 rights
    - Supplies to urban customers
    - Supplies by agreement
    - Associated entitlements
      - Delivery shares
      - Water-use licences
      - Section 67 licences

The EWR is the legally recognised amount of water set aside to meet environmental needs. The objective of the EWR is to preserve the environmental values and health of water ecosystems.

**Environmental water reserve (EWR)**
- The EWR is held by water corporations with secure tenure in perpetuity. They provide a share of inflows, storage capacity (if applicable) and releases.
- 'Above cap' water includes water that is left over after limits on diversions have been reached and unregulated flows which cannot be kept in storage. Most of the EWR is comprised of 'above cap' water, and this component is most susceptible to climate change.

**Bulk entitlements**
- Held by water corporations with secure tenure in perpetuity. They provide for water system operations, seasonal allocations and other rights and obligations.
- Bulk entitlements provide a set volume of water each year, subject to defined restrictions during periods of water shortages.

**Water shares**
- Water shares have secure tenure held in perpetuity. A share of the available resource in most regulated systems is allocated annually through seasonal allocations, which can then be ordered to a specified location, at a specified time and rate.

**Section 51 licences**
- Section 51 licences allow for diversions from unregulated (and some regulated main systems) and extractions of groundwater. Licences are issued for a specified volume, period of time and with a range of conditions.

**Section 67 licences**
- Section 67 licences provide for the construction of a groundwater bore or any works on a waterway, such as a private pump or dam, when a Section 51 licence is required.

**Section 8 rights**
- Section 8 rights provide for an individual to take and use water from a range of surface and groundwater sources for domestic and stock use without a licence.

**Supplies to urban customers**
- Supplies to urban customers must be provided by water corporations throughout their defined districts.

**Supplies by agreement**
- Supplies by agreement are arranged by water corporations to provide water outside of defined districts, and recycled and drainage water in special circumstances.

**Delivery shares**
- Delivery shares provide for water to be delivered to land via an irrigation district via a channel. Delivery shares are linked to delivery infrastructure and stay with the property if the water share is traded.

**Water-use licences**
- Water-use licences allow an irrigator to use water to irrigate land up to an annual use limit.

- Supplies by agreement are arranged by water corporations to provide water outside of defined districts, and recycled and drainage water in special circumstances.

- Delivery shares provide for water to be delivered to land via an irrigation district via a channel. Delivery shares are linked to delivery infrastructure and stay with the property if the water share is traded.

- Water-use licences allow an irrigator to use water to irrigate land up to an annual use limit.

- Section 67 licences provide for the construction of a groundwater bore or any works on a waterway, such as a private pump or dam, when a Section 51 licence is required.
In regulated systems, passing flows are the volume of water that water corporations must pass through its reservoirs before it can take any water for consumptive use.

In unregulated rivers (where there are no major dams that control releases) the EWR is provided primarily through management of existing diversions via licence conditions, rostering and restriction rules. In systems that experience increased ecological stress due to water extraction (especially in summer months) the focus is to ensure that appropriate limits are established and compliance arrangements are in place.

In the case of groundwater systems, the EWR cannot be quantified because it is not regulated the same way as surface water. Instead, groundwater extraction levels are set based on the need to protect groundwater dependent ecosystems and the rights of existing users. This occurs by limiting the volume or time of groundwater extraction for consumptive use.

4.2 Planning

a. Water Recovery

Water is a limited resource in Australia and with increasing competition for water resources there is simply not enough to maintain all the values dependent upon it. Water resource management and environmental water management must therefore work together to strike the right balance between supply of water for consumptive uses and water to maintain the environmental values of our rivers, estuaries and wetlands.

In Victoria, decisions to recover additional water for the environment are made through Regional Sustainable Water Strategies (SWS), which undergo a comprehensive consultation process with regional communities, water users and environmental managers to strike the right balance environmental and consumptive needs. There is a SWS for each of the four regions of Victoria (Central, Northern, Western and Gippsland) and they are reviewed every 5 to 7 years.

On a more local scale, management plans set out arrangements for sustainably managing available water resources in a system that balances the needs of all users, including the EWR. Kinds of management plans are:

- **Streamflow Management Plans**: manage water resources of unregulated waterways that are under stress, or where there is a demand for more development.

- **Groundwater Management Plans**: manage extractions from aquifers, prevent decline of the groundwater below a specified level, and clarify private groundwater users’ access.

- **Integrated water management plans**: recognise the connections between groundwater and surface water in systems with highly-connected groundwater and surface water.

- **Local management plans (non-statutory)**: capture and formalise existing rules in unregulated systems where there is no statutory management plan.
b. Identifying the required flow regime

Many of Victoria’s river systems are suffering from a long history of over allocation to consumptive users. Reduced flows can also impact on social and economic values such as recreation and irrigated agriculture by reducing the quality of the water to a point that it becomes unsuitable for use.

In many systems, the EWR is currently insufficient to maintain key environmental values as a result of water extraction for consumptive use and the cumulative impacts of the long dry period between 1997 and 2009. However, increasing the share of water to the environment in stressed systems can impact on existing water users and important economic activities such as irrigated agriculture. Achieving the right balance in water allocation decisions between consumptive use and water for the environment is therefore a difficult task. These decisions must seek to optimise outcomes for communities, regional economies and the environment wherever possible.

Victoria has developed techniques to determine how much water our rivers, wetlands and estuaries need to protect their health.

FLOWS method

The Victorian Government has a nationally recognised ‘best practice’ environmental flow assessment methodology (the FLOWS method) for determining the flow needs of rivers to help inform water allocation decisions. In the FLOWS method, a team of independent scientists determine the flow components that can support environmental values at a low level of risk. These values are identified in each river system by CMAs through the regional waterway planning process. Environmental flow studies using the FLOWS method have been completed for 42 rivers across Victoria and can be found at http://www.water.vic.gov.au/environment/rivers/flows/environmental-flow-studies

The FLOWS method describes key flow components as part of a recommendation for an environmental flow regime – rather than a minimum flow recommendation. The key elements of the FLOWS method are:

- the use of flow components to examine a flow regime
- a documented objective setting process that links environmental objectives to flow objectives and recommendations
- the use of a multidisciplinary environmental flows technical panel
- the definition of key hydrological tools for analysis
- the use of a hydraulic model as a tool in the interpretation and development of recommendations.

Environmental flows for Victorian estuaries

There is less information available about the freshwater requirements of estuaries than for rivers and wetlands. However, it is known that the inflow of freshwater from rivers or aquifers to estuaries is integral to their condition. It triggers fish breeding, helps to maintain an entrance to the sea,
ensures water quality meets a suitable standard and maintains associated floodplains and vegetation communities. To support management decisions the Victorian Government developed the Estuary Environmental Flows Assessment Method (EEFAM), a consistent and systematic approach to determine the environmental water requirements of estuaries. The Estuary Environmental Flow Assessment Method will be used to determine the appropriate environmental flow requirements of priority Victorian estuaries to inform water allocations decisions that may affect their health.

c. Integrated river health planning
The Government is developing the Victorian Strategy for Healthy Rivers, Estuaries and Wetlands (VSHREW) for release in 2012. The Strategy will replace the Victorian River Health Strategy (2002) and will present the strategic framework for river, wetland and estuary management in Victoria. The Strategy will put forward a more integrated approach to planning and incorporate themes of resilience and adapting to climate change.

The Regional River Health Strategies (to be replaced by regional Strategies for Healthy Rivers and Wetlands by 2013) are a key component of the VSHREW and are developed by catchment management authorities (CMAs). They provide short-, medium- and long-term condition and action targets for specific rivers, estuaries and wetlands. These targets can form the basis for setting EEFAM and FLOWs objectives. The aim of river health planning is to identify all threats to the system and prioritise management actions to ameliorate these threats. The VSHREW and EEFAM are designed on the basis that most rivers in Victoria are modified ecosystems, and are not aiming to return these systems to pristine or pre-European conditions.
5. EEFAM components and concepts

The concepts and components of the method need to be taken into consideration in applying the full EEFAM to estuaries in Victoria. This section explains the basis for the method and the rationale behind the steps that constitute the method. Section 6 describes the method itself and outlines the steps required to undertake an estuary environmental flow assessment.

5.1 EEFAM objectives

The primary objective of EEFAM is to define a flow regime required to maintain the ecological health of an estuary at a low level of risk (see Box 1). A flow regime comprises the elements of river hydrology which are significant to ecosystem health and which can be defined or measured hydrologically (Bunn and Arthington 2002).

The assessment of estuarine health as part of the EEFAM should consider past changes and possible future trajectories of the estuary, including regional river health strategy targets.

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.

A flow regime comprises the elements of river hydrology which are significant to ecosystem health and which can be defined or measured hydrologically (Bunn and Arthington 2002).

Riverine inflows influence the physical environment of the ecosystem: water chemistry, stratification and mixing, water level and habitat structure/diversity, temperature and exchange with the marine environment. They 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, cues for fish migration, life history processes and recruitment of plants and animals (Figure 2).
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 system prior to European settlement and which would be able to sustain these characteristics into the future.

A healthy estuary need not be pristine. Indeed, many of Victorian estuaries are highly modified through urbanisation, water extraction, ports and channelisation. 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.

A healthy estuary can still exist even though 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. An index of estuary condition is under development (for DSE by Deakin University) to assess the ‘naturalness’ or ‘health’ of an estuary based on its physical and chemical components, ecosystem functioning and biological communities. The index may provide important information on estuarine assets under flow stress.

Figure 2: Conceptual model of estuarine hydrology (from Oz Coasts 2008)
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 mostly determined through applying existing knowledge to the estuary. Objectives are set for specific ecological and geomorphological outcomes for a given level of estuarine health. Then, the flow components required to achieve these objectives are identified. These flow components represent a recommended flow regime (see Figure 3). The EEFAM framework seeks to maintain essential ecological functions but not to protect the full range of ecological processes.

The bottom up (or building block) approach (cf. King and Louw 1998) of EEFAM conforms with the asset-based approach of the Victorian River Health Strategy (NRE 2002a). EEFAM uses the same approach as FLOWS; together they can be applied in a single study of the entire length of a river system with consequent savings in cost and time.

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 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.

5.2 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. An estuary is essentially the last ‘reach’ of a river system, which highlights the role of upstream factors that influence the condition of the estuary. This definition has been adopted by the Department of Sustainability and Environment to identify and map Victoria’s estuaries (Barton et al, 2008).

Above the limit of tidal variation the FLOWS method can be used to describe environmental water requirements. Here, 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.

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 of EEFAM but 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.

5.3 Flow components

EEFAM is based on the assumption that biological or physical outcomes can be related to a suite of specific hydrological events (Poff et al 1997). EEFAM describes 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 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).

The flow components in EEFAM include:

- cease to flow periods (1)
- summer low flow periods (2)
- freshes (3)
- high flow periods (4)
- bankfull events (5)
- overbank flood events (6).

Non-freshwater aspects of an estuary flow regime include:

- tidal fluctuation
- storm surge
- dynamic entrance conditions
- dynamic salinity profile.

These components are considered in hydraulic modelling and outputs will inform the EEFTP on how ecological objectives can be met by each component.
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 may result in the upstream movement of the salt wedge, mouth closure 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 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 also 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.

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 (Cadwallader and Backhouse 1983; O’Connor & Mahoney. 2000; Crook et al 2006).

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. During summer–autumn periods, estuaries with a blocked entrance can be subject to anoxia, stratification and elevated water levels for prolonged periods.

**High flows**

High flows are defined hydrologically as the period of the year with elevated baseflows (winter and spring). Estuary inflows generally 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 may flush all salt water, including anoxic bottom waters rich in toxic ammonia and hydrogen sulphide, from the estuary and are therefore important to water quality. Entry of new, oxygenated marine water into the estuary when flows abate can be a trigger for spawning in many estuarine organisms (e.g. Newton 1996).

High flows also influence water level contributing to higher levels at high tide. High flows may have insufficient energy to open a closed estuary entrance, and they will contribute to the maintenance of estuary entrances that are prone to blockage. More than one high flow threshold may be specified.

**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 benthic habitats. 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 flooding are events which are not necessarily seasonally based. They result from unusually high rainfall periods which can occur at any time of year. Geomorphological outcomes are thus 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 EEFTP may decide to produce a prioritised set of flow components (as applied in other systems, such as flow studies on northern Victoria rivers; see LREFSP 2002; LREFSP and Humphries 2006; Anderson et al. 2008; Lloyd 2008; Cottingham et al. 2009; Cottingham et al. 2010; SKM 2010) to reflect the specific requirements and conditions of the system based on seasonal or inter-annual variations, estuarine values or needs of specific assets. While this may be desirable to do, it is seen as an additional task to the standard EEFAM and is used to inform environmental flow operations.

**5.4 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
- a community consultative committee (CCC) within which information is exchanged with the community.

These groups are coordinated by project managers (PMs) who administer the project from the point of view of the client (one of the SC) and the EEFTP.

**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, a relevant water corporation and other agencies (Figure 4). 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.
The Client Project Manager represents the Steering Committee in the day-to-day implementation of the project. 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, in some cases, 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>Stakeholder</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steering Committee</td>
<td>Project oversight&lt;br&gt;Selection and appointment of EEFTP and community consultative committee&lt;br&gt;Provision of data&lt;br&gt;Access to experts in their agency</td>
</tr>
<tr>
<td>Client Project Manager</td>
<td>Day-to-day management of project&lt;br&gt;Liaise with EEFTP Project Manager and the EEFTP&lt;br&gt;Coordinate the resources required to undertake the project&lt;br&gt;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&lt;br&gt;Provision of access to local knowledge and access to the estuary</td>
</tr>
<tr>
<td>EEFTP Project Manager</td>
<td>Day-to-day management of project and EEFTP&lt;br&gt;Coordination of field inspections and EEFTP workshops&lt;br&gt;Coordination of reporting</td>
</tr>
<tr>
<td>Estuary Environmental Flows Technical Panel</td>
<td>Establishes ecological and environmental flow objectives&lt;br&gt;Provision of expertise throughout the project&lt;br&gt;Involved in all key decisions and recommendations&lt;br&gt;Attends site inspections&lt;br&gt;Determines flow recommendations</td>
</tr>
</tbody>
</table>
Estuary Environmental Flows Technical Panel

EEFAM is implemented by an expert panel, the Estuary Environmental Flows Technical Panel (EEFTP), of which one member is the EEFTP 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 EEFTP should comprise specialists covering 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.
- groundwater hydrology to characterise the contribution of groundwater to estuarine inflows and ecology.
- physical estuarine limnology (oceanography) to characterise processes relating to water quality, biogeochemistry, microbiology, salt wedge dynamics, sediment/water column processes, stratification and estuary opening.
- geomorphology to set objectives for geomorphological processes and to recommend flows to achieve them.
- freshwater and estuarine 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.
- 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. Some members may provide expertise across more than one discipline. The size and composition of each EEFTP needs to be evaluated on a case-by-case basis as individual estuaries will have unique characteristics which require different levels and types of expertise.

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 EEFTP 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 EEFTP Project Manager is responsible for delivery of project outcomes according to the agreed scope and timeframe.

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).

The consultative committee of community, industry and cultural stakeholders has three roles:

• to provide the EEFTP with information which will support its investigations
• to consider and contribute to the objectives developed by the EEFTP
• to inform the wider community of the investigation processes and outcomes.

The Community 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.

5.5 Asset-based approach

EEFAM makes recommendations on the flow requirements of multiple ecological and geomorphological assets. This contrasts with earlier approaches which are less complex and rely upon one element such as fish habitat. Holistic methods like EEFAM and DRIFT (Downstream Response to Imposed Flow Transformation) (a South African method; Brown and King 2000; King et al. 2003; King and Brown 2006) address the water requirements of all biophysical aspects of a river or estuary (Arthington and Zalucki 1998; Arthington et al. 2004, 2006).

In EEFAM, assets are the plant species, plant communities, fish species, bird species or other faunal assemblages, as well as sites of ecological, geomorphological or cultural significance. A recommended flow regime for the estuary comprises the amalgamated flow requirements of these assets; it is built up from hydrology and hydraulics at representative transects agreed upon by all experts. Flow requirements are amalgamated through a workshop where conflicting and complementary flow requirements are identified and resolved.
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. 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
- areas with high levels of naturalness of components of the ecosystem.

It is important that representative assets are chosen that respond to a wide range of flow events and estuary mouth opening and salinity states.

Assets must also be selected with regard to available data. EEFAM relies heavily on the availability of detailed ecological 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. 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 summary, a comprehensive set of assets must be selected to encompass the freshwater inflow requirements of 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.

5.6 Conceptual models

Conceptual models will define the role of flow in directly providing for the habitat and other requirements of ecological assets and in driving other ecological, geomorphological and salinity processes. The models will be applied to estuaries to set ecological and environmental flow objectives as part of the methodology set out in Chapter 6.

The conceptual models will be maintained in a central library by DSE and will be transferable between estuaries. 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.
Models will be made available to the EEFTP Project Manager at the start of an EEFAM project. This will provide accumulated knowledge of previous EEFAM studies and will provide a consistent approach to determining hydrological objectives. Each model will have a universal component which documents applicable scientific knowledge, 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 conceptual models to individual estuaries. They are not off-the-shelf components of EEFAM but require expert opinion to be interpreted and applied. Ideally each EEFAM study will amend and improve models used. 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 may develop new models. 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.

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
- provide consistency to facilitate the review of EEFAM studies.

Generally these models should include a schematic diagram illustrating the role of flow in the habitat and ecological requirements, either as a graphic depicting the components and processes involved (often using Adobe Illustrator, and or another graphics package, and the IAN [see http://ian.umces.edu] symbol libraries) or a flow chart conceptual model (such as used in VEFMAP assessments (Cottingham et al 2005; Chee et al. 2008)).
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.

Vegetation conceptual models will:

• Include plant community structure and identify important component species.
• Describe the relevant components of the physical environment such as topographic setting, surface water regime (salinity and level), groundwater regime (level and salinity), wave exposure, geomorphological processes and soil type.
• Describe the tolerable limits and optima of flow-dependent physical conditions in terms of depth, salinity, temperature, residence time and any other flow-mediated physical parameter.
• Determine limits and optima from the scientific literature, local monitoring data and knowledge, and expert opinion. These limits 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 clearly specifying the relationship between flow components and responses that are expected to provide the habitat and ecological requirements of the vegetation should 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 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 below.

Figure 5: Example conceptual model for estuarine reedbed EVC.
Minimum standards – fish

Conceptual models will be developed for representative fish species. The models will:

• describe the major lifecycle stages which interact with estuary flows
• identify the habitat components used by the fish at each lifecycle stage
• describe the role of flow in providing tolerable or optimal conditions in each habitat
• describe the consequences of sub-optimal conditions.

Sources 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 should be prepared using Adobe Illustrator and the IAN symbol libraries. See an example in Figure 6. An alternative or additional flow chart conceptual model may also be developed for representative species to further illustrate the important ecology-flow relationships for that species (Figure 7).

Minimum standards – birds

Conceptual models of bird species or guilds will be required when their habitat requirements contribute to specific environmental flow recommendations. Similar to fish, the models must:

• describe the lifecycle stages which are influenced by estuary flows such as breeding, nesting and sourcing food
• identify the habitat components used by the birds at each lifecycle stage
• describe the role of flow in providing tolerable or optimal habitat for each habitat component
• describe the consequences of sub-optimal conditions, such as failure to breed or local extinction.

Sources used 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 should 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 physical laws, so that modellers can apply the functions to make numerical predictions. Where possible, any uncertainty concerning the predictive power of the relationships should be stated. All relationships need to be described in detail, including source(s) of original equation(s), units, and applicable realm. Conceptual models linking the deterministic sediment dynamics models to ecologically important processes will be required.

A schematic diagram illustrating the role of flow in geomorphological processes should 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 physical/chemical laws, so that modellers can apply the functions to make numerical predictions. Where possible, any uncertainty concerning the predictive power of the relationships should be stated. All relationships need to be described in detail, including source(s) of original equation(s), units, and applicable realm. Conceptual models linking the deterministic salinity dynamics models to ecologically important processes will be required.

A schematic diagram illustrating the role of flow in salinity processes should be prepared using Adobe Illustrator and the IAN symbol libraries. See an example in Figure 8.
Representative objective – common jollytail (Galaxias maculatus) – estuarine dependent (freshwater derived)

Common jollytails are a widespread and often abundant species in Australia; they are 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 below.

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 conditions through to very high salinities (well above that of sea water). They are also known to 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 5–6 months later (Treadwell and Hardwick 2003; McDowall and Fulton 1996 O’Connor & Mahoney. 2000; Crook et al 2006).

Reproduction

Common jollytails spawn amongst vegetation (grasses, samphire and other low vegetation) around estuary entrances 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 (low flow freshes) 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 (winter high 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.

Figure 6: Example conceptual model for Galaxias maculatus (common jollytail)
Figure 7: Alternative or additional conceptual model for Galaxias maculatus (common jollytail)
Representative objective – coastal saltmarsh (EVC 009)

Coastal saltmarsh occupies shallow depressions at the outer edge of the floodplain. It occurs within 4 km of the estuary entrance on parts of the floodplain that are regularly inundated by high water levels. In the lower part of the estuary, flood water is influenced by marine water and is more likely to be saline.

The depressions fill when estuary levels are high and the floodplain is inundated. This may be due to closure of the entrance, unusually high tides or flood flows. In contrast to the estuarine reedbed where water drains off the floodplain, water in coastal saltmarsh is captured in the depressions providing persistent flooding. There is little scope for seepage on the floodplain where the water table is shallow. Most water is therefore lost to evaporation and already brackish water will become more saline over time. The water filling the lagoons is most likely to be fresh in winter and spring when river flows cause flood events; it is more likely to be saline in summer and autumn when high estuary levels will be caused by closure of the entrance and estuary salinities are generally higher. High flows in the following winter flush salts from the depressions to some degree. The depressions therefore have a somewhat unpredictable water level and salinity regime. They are generally flooded in spring by brackish water and are generally muddy in summer when very high salinities will occur. Salinities tend to be higher near the estuary entrance where the marine influence is greatest. The retention level of the depressions appears to be approximately 1 m above the wetland bed. However, the depressions are broad and generally less than 0.5 m deep.

During spring the depressions support a diverse community of salt-tolerant wetland plants. When flooded in winter and spring a range of soft-leaved aquatic plants will be present including Ruppia maritima, Potamogeton pectinatus and the charophytes Chara sp., and Nitella sp. as well as filamentous algae (Breen 1982). Lower water levels in early summer will favour a range of herbland species, some of which will have initiated growth when flooded more deeply in spring. These species include Cotula coronopifolia, C. reptans, Selliera radicans, Triglochin striata, Mimulus repens and Distichlis distichophylla (Breen 1982). Schoenoplectus validus is a salt tolerant sedge which will also grow in this community in late spring and early summer.

Sarcocornia quinqueflora is also present in this community and is indicative of very high salinities. A comparative survey of groundwater-dependent vegetation in the south east of South Australia found this species in areas with the shallowest groundwater (approximately 0.4 m below the surface – although sites subject to regular flooding were excluded from this study) and the highest salinities (average 64,000 EC) (Ecological Associates 2006). Sarcocornia is likely to continue to grow actively in summer and autumn after other species in this community become dormant due to high salinities. Species that become dormant during this period, retreat to below-ground storage tissues and other resting stages.

Coastal saltmarsh provides a contrasting habitat for fauna to the fringing estuarine wetlands and estuarine sedgelands because of the dominance of submerged aquatic macrophytes and forbs, and the paucity of emergent macrophytes. Emergent species are excluded by the relatively higher salinities. Coastal saltmarsh species are adapted to variable flooding depths and will be relatively tolerant of prolonged closure of the estuary entrance.

Figure 8: Example conceptual model coastal saltmarsh (salinity regime).
5.7 Translating habitat requirements to hydrological and hydraulic thresholds

EEFAM relies on the translation of ecological requirements described in the conceptual models into hydrological events and hydraulic processes which can be analysed.

Thresholds must be identified which represent the point at which the habitat requirements are first provided. Example thresholds are presented in Table 2. When thresholds are identified, the mechanism to provide them can be determined.

Table 2: Examples of hydrological and hydraulic threshold measures.

<table>
<thead>
<tr>
<th>Habitat condition</th>
<th>Threshold measure</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</td>
<td>Hydrology: flow which achieves required entrance</td>
</tr>
<tr>
<td></td>
<td>dimensions</td>
<td>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</td>
</tr>
<tr>
<td></td>
<td></td>
<td>tide</td>
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<tr>
<td>Availability of saline water in estuary</td>
<td>Position of halocline</td>
<td>Hydrodynamic model to determine halocline position and</td>
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<td></td>
<td></td>
<td>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.

Peirson et al. (2002) provide a framework to identify and describe the linkages between habitat condition and flow components. The framework lists major physical and ecological processes and their sensitivity to inflow reductions (Peirson et al. 2002). The framework describes the role of flow in determining physical conditions (temperature, depth, dissolved oxygen and sediment transport) in the estuary. The significance of these features to estuarine flora and fauna is identified (see Figure 9 for an example).
Habitat condition – salinity tolerance of demersal fish eggs and large fish

Peirson process
LOW-1 increased hostile water quality conditions at depth

Hydraulic / hydrological tests – conditions to maintain minimum degree of mixing

Figure 9: The role of Peirson et al. (2002) processes in linking habitat condition to hydraulic and hydrological thresholds.

Peirson et al. (2002) describe 16 major physical and ecological processes (Table 3) that represent ecological responses to various flow components. These 16 processes were adapted from Bishop (1999) and are grouped by magnitude.

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 No.</th>
<th>Nature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>1</td>
<td>Increased incidence of hostile water quality conditions at depth</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive fauna</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive flora</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Extended durations of elevated salinity in the lower estuary allowing the invasion of marine biota</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Extended periods when flow-induced currents cannot suspend eggs or larvae</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Extended periods when flow-induced currents cannot transport eggs or larvae</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Aggravation of pollution problems</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Reduced longitudinal connectivity with upstream river systems</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Increased retention times in estuary reaches</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Nutrient influxes from density dependent saline surface water -shallow groundwater interactions</td>
</tr>
<tr>
<td></td>
<td>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>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>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>11</td>
<td>Reduced channel maintenance processes</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Reduced inputs of nutrients and organic material</td>
</tr>
<tr>
<td></td>
<td>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>14</td>
<td>Altered variability in salinity structure</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>Dissipated salinity/chemical gradients used for animal navigation and transport</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>Decreases in the availability of critical physical habitat features, particularly those components associated with higher velocities</td>
</tr>
</tbody>
</table>

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.
5.8 Hydrological analysis and hydrodynamic modelling

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

a) Hydrological analysis

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 EEFTP. 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)
- timing 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 occurs after the flow objectives and components have been defined, and the hydrodynamic characteristics 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. It contrasts with water that enters a stream or river rapidly, called stormflow, quickflow or event flow.

For event flow the frequency, duration and inter-annual variability will need to be characterised for the modelled natural series of events and the historic series (and future series). For baseflow components (summer low flows and winter high flows), characterisation of the monthly distribution of flow events (and including a measure of dispersion) will be required.

If hydraulic thresholds cannot be defined for baseflow components, the EEFTP 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 characterise the baseflow using descriptive statistics for each month or season.

b) Compliance testing of flow scenarios

The second phase of hydrological analysis includes calculation of compliance. Compliance is the degree to which the specified flow components occur in the flow series. Testing compliance of flow components in the natural scenario allows the EEFTP to reality check their expectations regarding required frequency and duration of their defined flow components.
A method of compliance analysis that suits the FLOWS method was published by Gippel et al. (2009), or the calculations can be performed using a spreadsheet provided as part of SKM (2007). These two approaches are similar, but there are important differences in the way compliance is expressed.

For each fresh, the SKM (2007) method determines the number of events in each year in the flow series of interest that satisfy the magnitude and duration requirements for the component. The number of years where the number of freshes is equal to or exceeds the frequency specified for the component are summed and divided by the total number of years in the series, and expressed as a percentage. Gippel et al. (2009) pointed out that this approach takes no account of the temporal distribution of the non-complying years. For example, a long sequence of non-complying years for a fish spawning fresh could be catastrophic for the species in question. Thus, a long-term frequency requirement was specified for each event component. This was stated as the number of years in every 10 years that the component had to comply. In this sense, ‘every 10 years’ means every sequence of rolling 10-year long periods in the record, not simply the record divided into discrete periods, each of 10 years length. The period length does not have to be 10 years - the EEFTP uses their collective expertise, combined with reference to the natural flow series, to establish a meaningful period length and required frequency. For example, if the EEFTP set the required inter-annual frequency at 5 in every 10 years, and a fresh component appeared in at least five years in every one of the sequences of 10 years in the modelled period, then the compliance would be 100%, while compliance of 50% would mean that in half of the rolling 10-year periods the component appeared in at least five of those 10 years.

For bankfull and overbank flow components the SKM (2007) method measured compliance as the number of years over the entire period of record with such an event relative to the expected number of years. This is necessary, because in FLOWS studies, bankfull and overbank are rarely specified to occur annually. The approach recommended by Gippel et al. (2009) for measuring compliance of events works for bankfull, overbank and fresh components. For bankfull and overbank components the required inter-annual frequencies will be lower than those specified for freshes. Gippel et al. (2009) did not mention the cease to flow component (as it did not occur on their test river), but its compliance can be assessed as for the event components.

For the baseflow components (low and high flows), the SKM (2007) method calculates compliance as the percent of time in the entire record (separately for each season) that flow equalled or exceeded the threshold specified by the flow recommendation. The method recommended by Gippel et al. (2009) calculates the percent of time in each year that flow equalled or exceeded the threshold specified by the flow recommendation, and compares this with an expected duration (specified as part of the flow...
recommendation). If the duration exceeds the expected duration then the component complies in that year. Then, as for the event components, the inter-annual compliance (specified as part of the flow recommendation) is calculated. This means that naturally dry years can occur without causing compliance to fall below 100% (as would occur in the natural series), unless there is a sequence of dry years, longer than the EEFTP considers tolerable for maintenance of ecosystem health.

The main difference in the compliance method of SKM (2007) and Gippel et al. (2009) is that the latter incorporates inter-annual frequency. Gippel et al. (2009) recommended specification of inter-annual frequency as one of the basic aspects of the flow regime. This was not included in the original FLOWS methodology, but represents a significant improvement because (i) the natural series should have 100% compliance, and (ii) in a managed regime, events and baseflows can be non-compliant in particular years (dry years) without negatively impacting the expected inter-annual compliance. The routine specifications made by the EEFTP are understood to apply to a year of average rainfall, and the inter-annual frequency specification allows for non-compliance in particular years as long as the sequence of non-compliant years is not too long.

Compliance testing should be undertaken on all available flow series. The standard flow series are natural (without development) and historic (historic level of water resources development). Other flow series that might be available are (i) assuming full development of water resources within agreed diversion limits, and (ii) allowing for climate change, which could be for a range of scenarios such as median, dry, wet, or step-change. Climate change scenarios would be run for a given assumed level of water resources development, so this might lead to the following scenarios for compliance testing:

- historic climate, no water resources development (natural)
- historic climate, current water resources development (historic)
- historic climate, full water resources development
- future climate, current water resources development
- future climate, full water resources development.

c) Analysis of shortfalls and risk

Failure to achieve 100% compliance means that there are shortfalls in supply to meet the recommended flow regime. These shortfalls could be related to chronic shortages of water (due to over-allocation or climate change) or they could be isolated instances of imperfect distribution of water. Implementation of an environmental flow regime may not always be possible to meet, so compliance may remain low. In systems that are not over-allocated, it may be possible to redistribute flows to meet consumptive demands and environmental flow demands.

Determining how to most efficiently allocate water requires a detailed water resources model, programmed to include environmental flow rules
This work would normally be undertaken by the authority responsible for managing the river. However, the EEFTP can rapidly estimate the shortfalls associated with their environmental flow recommendations using the eWater eFlow Predictor (www.ewater.com.au/products/ewater-toolkit/eco-tools/eflow-predictor/). eFlow Predictor is user-friendly software that diagrammatically represents river components: the source, environmental target, and delivery channel. The user enters flow components and rules associated with their implementation, plus the environmental and social ‘risks’ of meeting, or not meeting, each particular requirement. These factors are used to prioritise the flow components. The output details the augmented flow regime that satisfies the environmental requirements, compared to existing and natural conditions, plus gives summary statistics of the water allocation required. The SKM (2007) compliance spreadsheet will perform similar calculations, but eFlow Predictor is the more sophisticated tool.

d) Hydraulic modelling

Two hydraulic models are required.

A simple, one-dimensional flood model (such as HEC-RAS; Hydrologic Engineering Center - River Analysis System) is used to determine the flows required to achieve a range of water levels on the floodplains of estuaries.

A complex, two-dimensional vertical slice tide model (RMA - a proprietary hydraulic modelling package developed by Resource Modelling Associates - 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. (For full details and justification see Appendix D).

5.9 Variable flow recommendations: consideration of seasonal conditions and levels of environmental risk

The standard FLOWS and EEFAM methodology requires specification of a single set of flow recommendations. These flow recommendations apply to every season or year regardless of ambient flow conditions. Also, the method assumes that the management objective is always to attempt to provide flows that will maintain ecosystem health at a low level of risk.

This was recognised by Cottingham et al. (2007), who examined the distribution of desirable flow components, and undesirable flow stressors, in the natural series. The distributions were of particular aspects of the components or stressors, for example duration per year, magnitude of flow,
or magnitude of a habitat metric (called flow elements). Statistics were then provided on the percentiles of these flow elements.

An important statistic was the “median year” which was the 50th percentile value of the flow element, not the value of the element in the year with median annual flow. So for example, a flow stressor might be flow low enough that fine silt deposits on the bed. The flow element might be the duration (in days) per year that such conditions occur. The duration varies from year to year, and the distribution can be described in terms of percentile values. River managers are then free to set flows within this natural range, according to how much water is available.

Cottingham et al. (2007) also provided two groups of flow recommendations: (i) to achieve the environmental flow objective with a high degree of confidence or “low risk”, and (ii) to achieve the environmental flow objective with a “moderate risk”. The bounds associated with these two levels were based on best-available scientific information and the opinion of EEFTP members. Another example of how to derive flow options with different levels of risk was provided by Gippel et al. (2009).

The standard FLOWS and EEFAM recommendations are not as rigid as might be assumed. For example, the baseflow components (for both low and high flows) are normally specified with the ‘or natural’ rule. This means that if flows would naturally have fallen below the threshold set by the EEFTP, then the river flow can be set to this ‘or natural’ level. This rule would be employed in dry years. It essentially means that water could not be extracted from the river system when the flow naturally fell below the threshold.

As a way of sharing the water resource in dry periods, managers may choose to switch to a higher risk environmental flow option which would lower the baseflow threshold. Also, the method suggested by Gippel et al. (2009), which requires the EEFTP to specify inter-annual frequencies for all flow components, allows managers to lower flows below the thresholds in dry years without necessarily compromising the compliance.

The main issue for implementation of these flexible flow regimes is that triggers need to be developed for deciding when to release events, and when to switch to higher risk flow options. For management of event components to be sensitive to ambient flow conditions, all that is required is a trigger for each component. The trigger could be a modelled natural flow level, a gauged flow level, or a rainfall total; the trigger would only be relevant if the event in question had not occurred for a certain length of time (another parameter of the trigger).

To summarise, flexibility in implementation of flow recommendations can be achieved within the current FLOWS and EEFAM recommendation framework; all that is required is for the EEFTP to make specifications for inter-annual variability, provide multiple sets of flow recommendations corresponding to different levels of risk and seasonal climatic variability.
Specifying triggers for flow implementation will not be straightforward, and will likely need to be developed with the aid of a water resources model.

While the provision of climatically variable recommendations is desirable as an output of the method, they are not a prerequisite.

5.10 Minimum data requirements

Before an EEFAM study is commissioned, a minimum 30-year record of daily modelled flow (preferably the most recent 30 years of data) is required. This will enable a robust statistical examination of the frequency and duration of individual flow components. As EEFAM will compare inflow scenarios to inform water resource planning, a modelled flow series should be developed to include:

- natural flow (without development flows)
- historic flow (with current levels of entitlement utilisation)
- full development flow (historic flow with full entitlement utilisation)
- a worst-case climate change scenario (perhaps a continuation of the last 14 years of inflow – 1997–2010).

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
- aerial photos of the site
- photographs depicting flood extent on particular dates (These may be available from community members.)
- estuary water level gauging (to enable capture of the whole monthly tide cycle)
- survey benchmarks within the estuary reach.

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

5.11 Uncertainty

a) Uncertainties in the EEFAM process

Freshwater flow recommendations for an estuary are uncertain with respect to their objective, which is ‘to maintain the ecological health of an estuary at a low level of risk’. In this context, a healthy estuary is 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’. It is not possible to quantify the uncertainty in achieving this objective, because the pre-European state of the estuary cannot be accurately described, and future conditions affecting the estuary are hard to predict.
Stepping back a level in the EEFAM process to the hydrodynamic models, hydrological models, and flow-ecology and flow geomorphology relationships, it may be possible to quantify uncertainty in the outputs from these models. Model uncertainty analysis:

- demonstrates the range of possible outcomes
- improves the credibility of model output, and
- by providing a probabilistic forecast, rather than a single deterministic prediction, separates the scientific process of prediction from the management process of weighing up the consequences of possible events (Henderson and Bui, 2005).

Uncertainty is not specific to modelling of estuarine systems. Explicit consideration of modelling uncertainty is not a requisite of the FLOWS methodology, and its inclusion in the EEFAM process could lead to imposition of considerable costs. Qualitative evaluation of uncertainty by the modellers can be readily undertaken.

b) Types of uncertainty

Haimes (1998) described two main components to uncertainty: variability and knowledge uncertainty. Variability (or stochastic uncertainty) covers the intrinsic variability in the process being investigated and is independent of data collected or models fitted to the data. Knowledge uncertainty (or subjective uncertainty) is concerned with our incomplete knowledge of the process. This is reducible by collecting more of the right kind of data, and as knowledge of the process improves, better models can be developed and applied, and more informed parameter choices can be made (Henderson and Bui, 2005).

In statistical modelling, assumptions about the distribution of the error lead to confidence or prediction intervals for the output. However, it does not explicitly address uncertainty in the model structure or the input data set (Henderson and Bui, 2005). In deterministic modelling, such as application of a hydrodynamic model for a given scenario, uncertainty must be generated from assumptions about the uncertainty in the model inputs, parameters and structure (Henderson and Bui, 2005). Uncertainty in modelling arises from (Henderson and Bui, 2005):

- parameter uncertainty (selection of model parameter values)
- input uncertainty (measurement error in input data used in the model)
- model uncertainty (the chosen model structure)
- calibration data uncertainty (calibration represents the true process, but the data are subject to measurement error).

c) Quantifying predictive uncertainty

Beck (1987) and Matott et al. (2009) reviewed a wide range of model evaluation categories and analysis techniques used in uncertainty analysis, and Jakeman et al. (2006) provided a framework for evaluating uncertainty in environmental models. The objective of uncertainty analysis is to derive statements such as ‘a xx% error (uncertainty) in a driver will cause a yy%'
error (uncertainty) in a field (Beck 1987; Matott et al. 2009; Jakeman et al. 2006). This quantification will help characterise which drivers are needed for a good field prediction and can be very useful in model calibration by establishing data collection priorities (Blumberg and Georgas, 2008).

Henderson and Bui (2005) listed a number of potential approaches to quantifying predictive uncertainty, which is concerned with the effect of input data and parameter uncertainty on output uncertainty:

- Monte Carlo simulation
- generalized likelihood uncertainty estimation (GLUE) – a Bayesian Monte Carlo procedure
- Bayesian processor of forecast
- statistical emulators
- hierarchical modelling
- Bayesian melding
- other methods.

Henderson and Bui (2005) also discussed model calibration in the context of uncertainty.

Blumberg and Georgas (2008) developed a methodology to describe the effect of errors (or uncertainty) in the specification of certain drivers (bathymetry, river inflow, and wind speed) on the circulation computed by a three-dimensional estuarine and coastal hydrodynamic circulation model. They found that the main source of uncertainty related to the main control on circulation, which in tidally-driven estuaries was the bathymetry. In estuaries where the circulation is dominantly river or wind driven, the source of the uncertainty shifts away from bathymetry to these factors. The methodology of Blumberg and Georgas (2008) was based on first order variance analysis. For a one-dimensional estuarine hydrodynamic model, Willis et al. (1989) compared a method of uncertainty estimation using moment equations with Monte Carlo simulation experiments to demonstrate that for any spatial location in the estuary, (i) as the uncertainty in the channel roughness increases, the uncertainty in mean depth prediction increases, and (ii) the predicted mean depth will decrease with increasing uncertainty in Manning’s n.

Kennard et al. (2010) assessed the effect of record length on hydrologic metrics using data from Australia. They concluded that estimation of hydrologic metrics based on at least 15 years of discharge record is suitable for use in hydrologic analyses that aim to detect important spatial variation in hydrologic characteristics. The uncertainty reduced further up to a record length of 30 years, but beyond that the improvements were small.

Stewardson and Rutherfurd (2006) used a Monte Carlo analysis to quantify the effects of multiple sources of uncertainty on the environmental flow required to flush fine sediments from a gravel bed reach of the Goulburn River. The greatest source of uncertainty in this case was estimation of flow resistance (Manning’s n). It was suggested that the uncertainty could be
reduced by improving the resolution of the bathymetry data (more cross-sections), obtaining calibration data, and improving the sampling of the bed material. Of these, obtaining calibration data was the most effective, because it allowed direct estimation of Manning’s n.

Of the approaches to uncertainty estimation discussed by Henderson and Bui (2005), and listed above, Monte Carlo simulation is the most commonly applied. It involves assigning probability distributions to describe the uncertainty in the input data. A set of the potential model inputs is then obtained by sampling from each of these probability distributions in turn. If this is repeated a large number of times, the model output from each input set may be combined and used to construct a distribution that represents the predictive uncertainty (Henderson and Bui, 2005).

The focus of Monte Carlo simulation is on the input uncertainty. There is no direct attention to uncertainty attributable to model inadequacy or ignorance. Monte Carlo simulation can be computationally very demanding when there are even a moderate number of data or parameter inputs. Sensitivity analyses are often used to identify the most influential inputs and Monte Carlo simulation performed on that subset of inputs so as to reduce the computational burden (Henderson and Bui, 2005).

Sensitivity analysis might be considered a form of uncertainty analysis in its own right. Sensitivity analysis is a simple assessment to determine the relative effect each model input variable or parameter has on the simulated model results. Sensitivity analysis should be undertaken as a routine part of the modelling procedure for EEFAM. This step would not be overly time consuming, and would provide an immediate impression of the fitness of the input data for the purpose. Thus, the procedure would be to vary input parameters and input data across the realistic range that these might take to isolate those to which the model output is most sensitive. Once isolated, these parameters and/or input data could be varied across presumed ranges of error to provide some idea of the consequences of error. This procedure, although relatively simple, will provide a qualitative evaluation of the standard of knowledge regarding parameter values or input data and the implications of this for model output.

Uncertainty of model predictions for future conditions also includes variables that can change randomly, or in a planned way, in the future. For estuarine hydrodynamics these include:

- sea level rise due to climate change
- changed storminess, and thus storm surge frequency and magnitude
- hydrological change due to land use change
- hydrological change due to climate change
- hydrological change due to altered diversions, and new water resources developments.

The predictions concerning these variables are uncertain. It may not be possible for the EEFAM modellers to know the magnitude of the uncertainty
because the data concerning such scenarios are usually provided by a third party using complex models. The same applies to the basic hydrological ‘historic’ and ‘natural’ data series provided by REALM modelling. These are modelled on the basis of gauged flow data (which are uncertain, typically ±20% on any day), rainfall runoff modelling (highly uncertain), and knowledge of water use (highly uncertain).

A framework for considering uncertainty in the EEFAM process is suggested in Table 4. This framework is intended for low cost studies with tight time constraints. With increasing resources and time available, Monte Carlo simulation (or alternative) could be undertaken for all modelling steps. Even more effective would be to undertake field trials involving monitoring of natural or artificial hydrological events (Stewardson and Rutherfurd, 2006).

The framework in Table 4 allows the EEFTP to document why the current level of uncertainty is acceptable for the analysis, or why the additional information collected is sufficient to reduce uncertainty to an acceptable level. Uncertainties and assumptions on biological and/or physical data should be clearly documented and discussed (using the framework in Table 4) in the final report.

### Table 4: Components of the EEFAM process where uncertainty needs to be considered, and implications for the project if uncertainty is intolerable.

<table>
<thead>
<tr>
<th>Component of the EEFAM process</th>
<th>Approach to estimation of uncertainty</th>
<th>Implications for project</th>
</tr>
</thead>
</table>
| Flow-ecology, flow salinity and flow-geomorphology relationships | • Qualitative statement of uncertainty regarding the need for the flow objective to be satisfied in order to achieve good health.  
• Qualitative statement of uncertainty regarding the hydraulic/hydrologic criteria used to specify the objective (e.g. preferred depth and velocity ranges for particular species, or shear stress for sediment mobilisation). | If highly uncertain, the project needs to collect basic ecological data before proceeding. |
| Hydrological time series (flow data) | • Qualitative statement of uncertainty regarding the daily predicted flows for each scenario.  
• Flow records >15 years have acceptable uncertainty (Kennard et al. 2010). | If predicted daily flows are unavailable then REALM modelling (or similar) should be undertaken before proceeding. Modelling uncertainty should be described and justified as fit for purpose.  
If model is uncertain or only monthly, then model should be upgraded. If record length is <15 years then model should be upgraded. |
<p>| Tidal time series (inside estuary, and in marine environment) | • Qualitative statement of uncertainty regarding the measured levels for the desired locations. | Marine tidal data can usually be projected to site. If poor or no data available for the estuary, then monitoring is required for 2 months minimum. |</p>
<table>
<thead>
<tr>
<th>Component of the EEFAM process</th>
<th>Approach to estimation of uncertainty</th>
<th>Implications for project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empirical data concerning historical estuary opening/closing sequence</td>
<td>• Qualitative statement of uncertainty regarding dates of opening/closing, and completeness of record, as relevant.</td>
<td>If opening/closing relevant, a poor record will greatly increase uncertainty in the entire EEFAM process. This may be difficult to overcome, and will rely on adaptive management. This uncertainty should be described and assessed if it is consequential to the project (and therefore more data should be collected) or if it is assessed as not consequential to the project, this should be justified.</td>
</tr>
<tr>
<td>Bathymetry of estuary</td>
<td>• Qualitative statement of uncertainty regarding resolution and accuracy of data.</td>
<td>Bathymetry is important in tidally driven systems. This uncertainty should be described and assessed if it is consequential to the project (and therefore more data should be collected) or if it is assessed as not consequential to the project, this should be justified.</td>
</tr>
<tr>
<td>Climate data</td>
<td>• Qualitative statement on accuracy and completeness of record of rainfall, evaporation and wind data, if used in the hydrodynamic model.</td>
<td>Climate data are important if estuary closes, and if circulation is often wind and freshwater inflow driven. This uncertainty should be described and assessed if it is consequential to the project (and therefore more data should be collected); if it is assessed as not consequential to the project, this should be justified.</td>
</tr>
<tr>
<td>Water use data</td>
<td>• Qualitative statement on accuracy of data concerning extraction of water from the estuary, if relevant.</td>
<td>If water abstraction is significant relative to the volume of the estuary, then a poor record will increase uncertainty in the entire EEFAM process. Data need to be collected or modelled. This uncertainty should be described and assessed if it is consequential to the project (and therefore more data should be collected); if it is assessed as not consequential to the project, this should be justified.</td>
</tr>
</tbody>
</table>
| Hydrodynamic model | • Quantitative sensitivity analysis to identify the parameters/input variables to which the model output is most sensitive.  
• Quantitative sensitivity analysis to determine the impact on model output of varying the sensitive parameters/input variable values across their possible range.  
• In highly controversial situations, Monte Carlo or alternative approach to quantifying uncertainty in model outputs. | Reduction of high uncertainty may require collection of more input data. This uncertainty should be described and assessed if it is consequential to the project (and therefore more data should be collected) or if it is assessed as not consequential to the project, this should be justified. |
5.12 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 allow for seasonal data to be collected and workshops and iterations to be organised between the professionals involved in the project.
- The conceptual understanding of the hydrology, geomorphology, and ecology of the system is reasonably well-known; and habitat and ecological requirements of the system’s key assets can be clearly linked to freshwater flow components.
- Modelling calibrations are appropriate.
- The EEFTP has an appropriate level of knowledge and expertise.

Assumptions used in the EEFAM study should be documented to enable transparency, future learning and adaptive management (see section 6).
The EEFAM specification is made up of 9 steps described in the Figure 10 below:

**Figure 10 EEFAM**

1. **EEFTP Engagement**
   - **Preliminary Tasks**
     - Project Establishment

2. **Characterisation of Estuary Environment**
   - 2A. Hydrological and Hydrodynamic Characterisation
   - 2B. Groundwater Characterisation
   - 2C. Ecological & Geomorphic Characterisation

3. **Site Paper**

4. **EEFTP Site Inspection and Workshop**

5. **Issues Paper**

6. **Model Interrogation**

7. **Scientific Panel (EEFTP) Workshop**

8. **Environmental Flow Recommendations**

9. **Final Report and Presentation to Stakeholders**
Tasks prior to the actual EEFAM study, which are the responsibility of the Steering Committee, are labelled A and B; the tasks for the EEFTP are numbered 1.1 to 9.1 to reflect the steps involved in the EEFAM itself. This sub-division will facilitate the preparation of a project brief for the EEFTP.

6.1 Preliminary tasks – project establishment

Objective: To establish the objectives and management arrangements for the project and select and appoint the EEFTP.

**Timeframe:** 3 months

**Task A: Convene Steering Committee**

The EEFAM investigation is managed by a Steering Committee. The Steering Committee determines the scope of the investigation, appoints the EEFTP and supervises delivery of the project. The Steering Committee delegates day-to-day executive supervision of the project to the Client Project Manager.

The Steering Committee comprises natural resource managers and agency staff who have responsibility for the ecological health and management of water in the estuary. It typically comprises representatives from DSE (Sustainable Water and Environment Division), the catchment management authority, relevant water corporations and other agencies.

The initial meeting of the Steering Committee determines the required outcomes of the estuary study and how they will be addressed by EEFAM. Prior to the meeting, the Client Project Manager collates and summarise available information in a briefing paper for the Steering Committee. The purpose of the meeting is to agree on:

- the values of the estuary
- threats to those values
- community stakeholders in values and threatening processes
- current and future management pressures and priorities
- a vision for the desired condition of the estuary
- the existing state of knowledge of the hydrology, ecology, hydraulics and geomorphology of the system
- the requirements of an EEFAM investigation to provide:
  - information and data to support future decision making, and
  - specific management guidance
- the timeframes required by decision makers in relation to the timeframes indicated in EEFAM
- the funds available for the project.
The Steering Committee must decide whether the existing state of knowledge is adequate for EEFAM or whether preliminary technical investigations should be undertaken before EEFAM can commence. In particular, a minimum 30-year record of daily modelled flow (preferably data from the previous 30 years) is required and a modelling series available including:

- natural flow (without development flows)
- historic flow (with historic levels of entitlement utilisation)
- full development flow (historic flow with full entitlement utilisation)
- a worst-case climate change scenario.

There also needs to be available flora and fauna information for the site, water quality data and other information necessary to enable the site to be characterised.

The meeting provides guidance for the Client Project Manager to prepare a scope of work for the EEFAM investigation and to convene the Community Consultative Committee (CCC).

Task B: Prepare scope of work and engage EEFTP

The Client Project Manager prepares a brief to engage the EEFTP. The brief is approved by the Steering Committee.

Submissions are invited from suitably qualified consultants to undertake the work.

The EEFTP is appointed by the Steering Committee.

6.2 Step 1 – EEFTP engagement

Objective: To engage the EEFTP and establish the working arrangements for the project.

Timeframe: 1 month

Task 1.1 Initiation meeting

The Steering Committee convenes a meeting with the EEFTP to review the scope of work and how it will be addressed by the EEFTP.

The Client Project Manager presents the overall policy objectives for the estuary and summarises the threats, values and management pressures on the system. The current state of knowledge is presented.

The EEFTP Project Manager presents how EEFAM will be applied to the site and presents the roles of the EEFTP members. The timelines for project tasks are agreed. The Client Project Manager hands over available data to the EEFTP including reports, data and other resources listed in the brief (see Task A). Key information resources 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
• areas with high levels of naturalness of components of the ecosystem.

Key stakeholders are identified and arrangements are made for liaison with the Community Consultative Committee.

Task 1.2 Initial Community Consultative Committee meeting
The Client Project Manager convenes the first meeting of the CCC with representatives of the EEFTP. These must include the EEFTP Project Manager, an ecologist and a physical scientist from the team. The Client Project Manager will explain the objectives and scope of the project and the activities and timeframes involved.

The EEFTP Project Manager will explain the methodology and the roles of the EEFTP members.

The community representatives explain their interest in, knowledge of, and concerns for the estuary. Representatives should provide any hydraulic, hydrological or ecological information which may be helpful to the project. These may include:
• photographs indicating tide levels or flood extent which may assist in calibrating hydraulic models
• fish catch records
• water levels records, and/or
• flora and fauna records.

Community members are informed of the value of these records and procedures are established to provide them to the project.

Task 1.3 Initial site inspection
An initial inspection of the estuary is conducted to familiarise the EEFTP with the site, its extent and its key features. 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. An estuary is essentially the last ‘reach’ of a river system. The lateral boundary of the study area is the extent of inundation at the highest known water level in the estuary.

The initial inspection can be combined with the initiation meeting and the initial CCC meeting. It will provide a physical context for issues raised at these meetings. The inspection includes as a minimum:
• the Client Project Manager
• the EEFTP Project Manager (who may also be one of the specialists below)
• the hydraulic modeller
• the hydrologist, and
• an ecologist.
It may also include Steering Committee members with specific technical knowledge of gauging, monitoring or management information, and CCC members. Other EEFTP members may attend but this is not essential at this early stage.

**Step 1 outputs**
- established working arrangements
- data handover
- initial site inspection.

### 6.3 Step 2 – Characterisation of the estuary environment

**Scope:** To characterise the physical and ecological environment of the estuary.

**Timeframe:** Six months: approximately 3 months of data collection (provided high and low flow periods are captured, a longer period may be required) followed by 3 months of model development.

**Task 2.1 Collate and review data**

EEFAM uses a two-dimensional tide model (RMA 2DV hydrodynamic model or equivalent) to model tidal fluctuations in the estuary channel and a one-dimensional flood model (HEC-RAS or similar) to evaluate freshwater flood events.

The process to develop these tools and their roles in EEFAM is presented in Figure 11.

**Figure 11: Flood model and tide model.**
To determine the scope of data collection for the models, the EEFTP hydraulic modeller and hydrologist review available data. This includes data handed over at the initiation meeting and other resources the team can access including:

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

A brief summary of existing data and data collection priorities (as well as a justification of new data to be collected) is prepared and provided to the Client Project Manager. (Note: the data should support an assessment of the flow components which include at least cease to flow periods; summer low flow periods; freshes; high flow periods; bankfull events and overbank flood events.)

A description and documentation of the uncertainties and assumptions to be used in the project should be made as part of this summary. Any uncertainty should be described and assessed if it is consequential to the project (and therefore more data should be collected). If uncertainty is assessed as not consequential to the project, this should be justified (examples are given in section 5.11).

**Task 2.2 Site assessment**

A meeting is held between the Client Project Manager, EEFTP Project Manager, hydrologist and hydraulic modeller. The requirements to collect data to support the project are discussed and a plan is agreed on to prepare a detailed scope for investigations.

A detailed site assessment is conducted to plan the collection of physical data to support the flood and tide models. The models must report on thresholds of significance to ecological processes, water quality and geomorphology. The site assessment is led by the hydrodynamic modeller and is attended by the ecological and physical science team members.

The site assessment identifies and describes 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. A boat may be required. The hydraulic modeller will gain a conceptual understanding of estuary function that will later be developed into a quantitative model.
Vertical profiles of temperature, salinity and dissolved oxygen are collected. A simple longitudinal bathymetric profile is determined. The use of a depth sounder might be sufficient to collect this data. In large or complex estuaries, the longitudinal profile might need to be determined professionally.

The hydrodynamic modeller will select the location and orientation of survey cross-sections required to capture the hydraulic environment of the estuary. The cross-sections will also be selected to provide detailed output for key hydraulic thresholds identified by the ecological and physical scientists such as:
- floodplain inundation
- backwater connectivity
- areas of mixing, dilution or flushing
- sediment dynamics
- depth of water or velocity at sills and reefs.

The site assessment will thus determine sites and methods for the collection of data to support the hydraulic model, most importantly:
- water level gauging in relation to tides and estuary inflows
- salinity dynamics monitoring
- surveyed cross sections
- a longitudinal bathymetric profile.

**Task 2.3 Data collection plan**

A data collection plan is prepared and reviewed by all EEFTP members. The data collection plan will outline any requirements for the timing and sequencing of data collection (see task 2.4 below for details). The final data collection proposal will be presented to the Client Project Manager for approval.

**Task 2.4 Data collection**

The data collection plan is implemented by the EEFTP.

The EEFTP prepares one or more briefs to engage contractors to collect the field data.

The cross-sectional survey brief must be prepared in accordance with the specifications in Appendix D. The brief is submitted as a draft to the Client Project Manager so that any additional client requirements for data format or metadata can be included. A surveyor is then engaged to undertake the work.
In addition, the data collection program addresses the following minimum data requirements:

- automatic water level gauging at sites within the estuary and outside the estuary over a period of at least 30 days and ideally 60 days (to capture one to two tidal cycles)
- at the same time as tide gauging, continuous stream discharge gauging
- a longitudinal bathymetric profile
- salinity, temperature and dissolved oxygen measurements at four to six locations at a range of depths over a period of at least two days for model calibration.

In simple cases, this data may be collected by the EEFTP. In complex systems, specialist contractors might be required.

A detailed specification for these investigations is provided in Appendix D.

6.4 Step 2A – Hydrological and hydrodynamic characterisation

Task 2A.1 Flood model development

A one-dimensional flood model is developed using the cross-sectional survey data. The model will later draw upon the refined and calibrated channel roughness estimates developed during the development of the tide model (see below and Appendix D).

The flood model:
- quantifies the bankfull capacity of the estuary channel
- estimates flood levels through the estuary and supports the interpretation of ecological processes.

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

The only input required for the flood model is the cross-sectional survey data. It should therefore be completed early in step 2.

Task 2A.2 Tide model development

When the initial version of the flood model is complete and the data collection program has concluded, a two-dimensional vertical slice tide model is developed using RMA-10 or an equivalent hydrodynamic software package (Appendix D) 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.
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 12). The model is run to demonstrate estuary sensitivity to:

- two entrance area conditions (open or intermediate)
- 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)
- the downstream boundary (using a repeating spring–neap tidal cycle).

The parameter specifications above define eight basic model runs (2 x entrance area, 4 x constant inflow) and six 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
- flow required to flush the estuary of salt.

**Figure 12: Simulation schedule for the tide model.**
The following outputs are provided from the sensitivity analysis:
- animation of the longitudinal salinity profile under the various scenarios
- a snapshot of the salinity structure (one each on the ebb and flood tide – see Figure 13)
- a time series variation of vertical salinity profiles (top, middle and second from bottom layers) at four to five discrete locations along the estuary
- variation in velocity (top, middle and second from bottom layers) at four to five discrete locations along the estuary
- saline recovery
- residence time.

The tide model is 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 run at representative flows such as 80%, 100% and 120% of the bankfull discharge, with flow held at this level for 1 to 2 weeks. The flushing flow analysis provides:
- an animation of the longitudinal salinity profile
- salinity time series extracted from near the estuary entrance for each scenario.

A detailed specification for these investigations is provided in Appendix D.

Figure 13: The tide model provides snapshots of the salinity structure on the spring and flood tides (from Lloyd et al. 2008b).
Task 2A.3 Hydrological characterisation

Daily flow data is summarised to provide an initial hydrological characterisation of the estuary. This task reports the basic hydrological type of the estuary and the range of event magnitudes, frequencies and durations typical of the estuary. 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 (also see below). These analyses allow the EEFTP to gain an understanding of the basic character of estuary inflows, their relative size and their distribution through time.

At this stage it is not possible to characterise the frequency and duration of events of particular magnitudes 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 following basic analyses are required.

- **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 – fresh or saline). The spells of events of negative hydrological balance are characterised.

- **Monthly flow distributions of selected flow indices**. These are selected by the hydrologist to suit the requirements of the EEFTP members, but important basic statistics include median flow, flow exceeded 5% of the time (high flow index) and flow exceeded 95% of the time (low flow index). Other statistics may be required by the hydrodynamic modeller. The objective is to provide a characterisation of flow seasonality and some idea of typical flow magnitudes for the system. If alternative catchment flow scenarios are available, the scenarios are used to report the degree of deviation from the benchmark case (normally the modelled natural flow series).

- **Flood series analysis**. This is an annual series of partial duration series analysis, using peak instantaneous flow data if available (not available for REALM modelled flows). A partial duration series is composed of all events for the specified period that exceed various criteria (matching flow components). 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.

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

- **Flow separation using a numerical filter and rules for defining periods when flows are ‘predominantly baseflow’ and ‘predominantly quickflow’**. This is required if baseflow components are defined on the basis of hydrological (as opposed to hydraulic) thresholds. 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.

### 6.5 Step 2B – Groundwater characterisation

**Task 2B.1 Data collection**

If groundwater investigations are included in EEFAM, basic data on groundwater should be collected concurrently with other field work. The scope of groundwater investigations is limited to the characterisation of aquifers which directly influence the salinity or soil moisture environment of environmental assets. In most cases, this will 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 locations. If piezometers are required, their installation must be completed early in the data collection program.

- Piezometers must be installed prior to the physical survey (step 2A above). 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.

- Piezometers must be installed prior to the gauging of water level and stream discharge (task 2.4 above) so that groundwater dynamics may be related to estuary levels.

A longer groundwater monitoring record will increase the capacity to describe seasonal groundwater variation and to relate estuary dynamics to trends reported from existing regional groundwater monitoring networks.

**Task 2B.2 Groundwater characterisation**

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 characterisation 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.

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

It would 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. It is important that these ecologically important processes are raised in the first field trip workshop to provide appropriate guidance to the hydrologeologist as the site paper is prepared.

6.6 Step 2C – Ecological and geomorphological characterisation

Task 2C.1 – Geomorphology

The geomorphology of the estuary is characterised in terms of:

- 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
- 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), making reference to the NLWRA (National Land and Water Resources Audit) predictions for the river (see http://www.anra.gov.au/topics/soils/

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 EEFTP members regarding the geomorphological processes and forms that have known links to ecological health.

Task 2C.2 Vegetation

The vegetation communities and significant species in the estuary are described 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.

Task 2C.3 Fish

The fish fauna of the estuary are described. Information sources will include the Atlas of Victorian Wildlife, records from local naturalists and anglers and scientific research. The key habitat requirements of these fish must be identified from a review of the behaviours, habitats and life history requirements. Habitat requirements may be described for species individually or for functional groupings such as:

- estuarine resident fish
- estuarine dependent fish
- estuarine opportunists (Hindell pers. comm. and Arundel 2006).

Fishes are selected from each functional group to collectively:

- Represent a wide variety of habitat requirements which are sensitive to flow and water management in the estuary.
- Include species for which there is a significant knowledge base.
- Include species of conservation significance (listed under Flora and Fauna Guarantee or Environment Protection and Biodiversity Conservation Acts) or management (fisheries valued species) frameworks, or as specified by local management plans, Victorian bioregional and statewide frameworks, Commonwealth legislation or local community stakeholders.
For the selected species, information should be collated on all aspects of life history which interact with flow, including requirements for breeding, spawning, juvenile development, dispersal, migration, predation, shelter and resting. Information is required on the physical habitat conditions of each stage and should be described in terms of 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 seagrass meadows, access to the floodplain and access to upstream riverine reaches.

Task 2C.4 Birds
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.

Step 2 outputs
• Flood model
• Tide model
• Groundwater characterisation
• Ecological characterisation

6.7 Step 3 – Site paper

Objectives: To provide the policy and management setting, and document the known state of the estuary.

Timeframe: 1 month.

Task 3.1 – Policy context for environmental flow objectives
The flow recommendations made by EEFAM must be founded on established environmental policies for estuaries and water resource management. 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, as recommendations may be challenged when they conflict with other natural resource interests.

Key documents, policies, strategies and plans that provide the strategic setting to every EEFAM study are listed in Appendix B. These will include the proposed Victorian Strategy for the Health of Rivers, Estuaries and Wetlands. Regional and local policies, such as ecological character descriptions for Ramsar sites, will provide more specific guidance.

The site paper reviews and summarises these policies insofar as they guide environmental water management and water resource sharing.
Task 3.2 – Water resource management
The site paper must describe how the surface water and groundwater resources of the catchment are managed and operated including (but not limited to):
• the location of water storages for urban or irrigation use including their volumes, operating arrangements and any passing flow requirements
• the location and history of gauging stations
• the volume and delivery arrangements for environmental entitlements, if any
• the nature and degree of water development and use. This should include such things as indicative numbers and volumes of farm dams; domestic and stock licences; and the number and volume of diversion and groundwater licences and any of their general operating conditions that may affect the management of the river and estuary.
• water management planning areas (e.g. groundwater management plans and streamflow management plans).

Task 3.3 Present physical and ecological characterisations
The outputs from the stage 2 are presented in the site paper including:
• the flood model, tide model, hydrodynamic characterisation and salinity characterisation
• groundwater characterisation
• geomorphological characterisation
• ecological characterisation including fish, vegetation and birds.

Task 3.4 Nominate assets for conceptual models
In the site paper, the ecological characterisations must nominate the assets for which conceptual models will be developed. The model assets must be selected to comprehensively represent the full range of ecological assets identified in tasks to this point (especially step 2C).

Step 3 outputs
• policy context for environmental flow objectives
• water management context
• flood model, tide model, hydrodynamic characterisation and salinity characterisation
• groundwater characterisation
• geomorphological characterisation
• ecological characterisation including fish, vegetation and birds.
6.8 Step 4 – EEFTP site inspection and workshop

Objectives: To review the physical functioning of the estuary and determine the modelling resources available to assist with environmental flow determinations

Timeframe: 2 weeks (site inspection expected to take 2 days but dependent on size of system).

Task 4.1 Community Consultative Committee
EEFTP 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.

Task 4.2 Field review and workshop
A field inspection will be conducted to review the data and modelling resources compiled by each of the team members, in the context of the field setting. 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, deep basins, 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 salinity dynamics in the channel and in floodplain depressions.

A workshop of the EEFTP is required after the site inspection to draw together the issues important to the study. Each team member is required to describe the flow-dependent features or processes of management significance and to identify linkages to other disciplines. 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. 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 5 below.
Table 5: 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 periodically inundated 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 are to be investigated.</td>
<td>Geomorphologist</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydrodynamics of floodplain inundation are to be reported.</td>
<td>Hydrodynamicist</td>
</tr>
<tr>
<td></td>
<td>Seagrass beds require a particular salinity regime.</td>
<td>Salinity tolerances of seagrass beds are to be defined.</td>
<td>Plant ecologist</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Salinity regimes are to be characterised.</td>
<td>Hydrodynamicist</td>
</tr>
<tr>
<td>Fish</td>
<td>Salt wedge position is 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 the estuary.</td>
<td>Fish ecologist</td>
</tr>
</tbody>
</table>

This process links the ecological functions and processes in the estuary to the physical conditions that support them. Discussion among the team is essential to specify the required physical conditions as clearly as possible. Ecologists will advise on the required timing, frequency, location and aquatic conditions for ecological processes; the physical scientists will indicate where these conditions are provided and when they are likely to occur.

The discussion will identify issues for further investigation by the ecologists and physical scientists. The physical scientists will ask the ecologists to specify ecological events in detail in order to describe them with thresholds and statistics from models and other data. The ecologists will ask the physical scientists to provide statistics and data that verify the occurrence of physical conditions they believe are ecologically significant. In both cases, the team members will determine the additional data they require from each other to develop environmental flow recommendations in the issues paper.

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 one day, with a one-hour workshop held at the end of the day.

**Step 4 outputs**
- Plan established for the scope of the issues paper and for sharing of information in its preparation.
6.9 Step 5 – Issues paper

Objective: To describe the state of the estuary with regard to policy objectives and to present ecological and geomorphological objectives for the estuary with preliminary estimates of the hydrological requirements.

Timeframe: 1 month

Task 5.1 Issues paper development

An issues paper is prepared to establish the hydrological, geomorphological and ecological objectives for the study. Conceptual models are prepared for each of the assets nominated in the site paper, which may be species, communities or assemblages. The conceptual models describe the role of the estuary water regime in the growth, dispersal, survival or other process of the group in question. They identify key objectives for the ecological, geomorphological and salinity functions of the estuary.

Relevant models are 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 such as elevation and position within the estuary to allow measurable hydrological and hydraulic thresholds to be identified. The thresholds will 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 help link the ecological and physical objectives of the models to the driving hydrological and hydrodynamic processes.

For each flow event, the required timing, frequency, duration, and maximum interval period 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 will 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.
Task 5.2 Presentations

The issues paper is 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 the EEFTP Project Manager to the Community Consultative Committee (CCC) and Steering Committee (SC) will allow feedback to be received and will incorporate comments, improvements, and concerns to finalise the issues paper.

Step 5 outputs

- Issues paper
- Conceptual models
- Draft ecological and geomorphological objectives
- Draft hydrological objectives

6.10 Step 6 – Model interrogation

Objective: To determine quantitative thresholds so that descriptive statistics may be extracted from the hydrodynamic model and hydrological data.

Timeframe: 2 months

Task 6.1 Determine thresholds for ecological and geomorphic objectives

In preparing draft hydrological objectives for the issues paper, the ecologists and geomorphologists made informed estimates as to the magnitude, frequency or duration of the hydrological events that support ecological and geomorphic objectives. The hydrological objectives are informed by the hydrological and hydraulic information in the issues paper. They are estimates because this information relies on interpretation of ecological and geomorphic requirements.

The tide model, flood model and hydrological analysis are developed to provide accurate and specific data to describe the hydrological objectives. However, to extract the necessary information, the ecologists and geomorphologist must express hydrological requirements in terms that the hydrodynamic modeller and hydrologist can use.

An internal workshop is held to agree on the terms used to describe hydrological requirements. Each of the conceptual models developed in the issues paper, and their ecological objectives, is presented. The physical conditions (hydrological, water quality or hydraulic) that support them are presented in general terms.

The EEFTP then draws on the available information to define these conditions as specifically as possible, such as:
- the exact elevation for a water level threshold
- the exact salinity or salinity range of interest
- the specific velocity or velocity range for a flow
• the position in the estuary where the conditions must be provided (i.e. which surveyed cross-section)
• the specific month or months when the conditions must be provided.

This process, from general to specific, can be documented in table format (see Table 6). As this process is completed for additional models, it will become clear that thresholds may be applicable to multiple objectives. For example, ‘water level exceeds 1.2 m AHD for 6 weeks at cross-section 4 in between May and September’ may be relevant to fish, bird, water quality and geomorphology objectives. These commonalities can only be identified in a workshop discussion. They greatly simplify both model interrogation and flow recommendations.

Table 6: Ecological and hydrological objectives for coastal salt marsh (example only, taken from Gellibrand EEFAM pilot study, Lloyd et al. 2008b)

<table>
<thead>
<tr>
<th>Physical habitat component</th>
<th>Role of habitat component</th>
<th>General conditions required</th>
<th>Specific physical thresholds</th>
<th>Possible assessment approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth and extent of floodplain depressions</td>
<td>Retain water from high estuary levels, local rainfall</td>
<td>Geomorphic processes to maintain depression depth of approximately 0.5 m and current extent</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Flooding by saline water in summer and autumn</td>
<td>Promote salt-tolerant charaphytes, herbs, grasses and forbs; exclude emergent macrophytes</td>
<td>Peak salinity (between refreshing events) of 7.5 to 20 in summer and autumn in depressions</td>
<td>Median salinities in shallow (&lt;1 m deep) estuary water downstream of cross-section 10 (XS10) exceeds 5 in summer and autumn</td>
<td>(Assume salinisation of water detained in floodplain depressions by evaporation) Median salinity of water &lt;1 m deep downstream of XS10 on seasonal basis.</td>
</tr>
<tr>
<td>Flooding by brackish water in winter and spring</td>
<td>Promote salt-tolerant charaphytes, herbs, grasses and forbs; exclude emergent macrophytes</td>
<td>Peak salinity (between refreshing events) of 5 in winter and spring in depressions</td>
<td>Median salinities in shallow (&lt;1 m deep) estuary water downstream of XS10 exceeds 3 in winter and spring</td>
<td>(Assume salinisation of water detained in floodplain depressions by evaporation) Median salinity of water &lt;1 m deep downstream of XS10 on seasonal basis.</td>
</tr>
</tbody>
</table>
### Table 6: Ecological and hydrological objectives for coastal salt marsh continued

<table>
<thead>
<tr>
<th>Physical habitat component</th>
<th>Role of habitat component</th>
<th>General conditions required</th>
<th>Specific physical thresholds</th>
<th>Possible assessment approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Persistent flooding in winter and spring by fresh / brackish water</td>
<td>Promote salt-tolerant charaphytes and submerged vascular macrophytes; exclude emergent macrophytes</td>
<td>Persistent flooding to depth of 0.25 to 0.5 m (predominantly 0.5 m) from May to October</td>
<td>Median interval between events where water level at XS10 exceeds 1.0 m AHD is 2 weeks in May to October</td>
<td>Median interval between events exceeding thresholds at XS10, reported separately for winter / spring and summer / autumn</td>
</tr>
<tr>
<td>Shallow flooding in late spring / early summer</td>
<td>Provide habitat for salt-tolerant grasses, sedges, herbs and forbs</td>
<td>Average water level from November to December is 50% of average water level from August to September</td>
<td>Median interval between events where water level at XS10 exceeds 1 m AHD is 3 weeks in summer and autumn</td>
<td>Median interval between events exceeding thresholds at XS10, reported separately for winter / spring and summer / autumn</td>
</tr>
<tr>
<td>Intermittent flooding in summer and autumn</td>
<td>Maintain Sarcocornia quinqueflora</td>
<td>Depressions less than 20% of maximum depth 80% of the time over summer autumn</td>
<td>Median interval between events where water level at XS10 exceeds 1 m AHD is 8 weeks in summer and autumn</td>
<td>Median interval between events exceeding thresholds at XS10, reported separately for winter / spring and summer / autumn</td>
</tr>
<tr>
<td>Waterlogging by saline groundwater in summer and autumn</td>
<td>Maintain Sarcocornia quinqueflora</td>
<td>Groundwater depth less than 0.4 m to maintain evaporative concentration of salts in surface soil; groundwater salinity 10 to 60</td>
<td>No assessment possible</td>
<td></td>
</tr>
</tbody>
</table>

This process:
- expresses hydrological objectives in a clear format which can be readily investigated by the hydrologist and hydraulic modeller
- aligns, as far as possible, the hydrological objectives with the actual hydraulics, salt dynamics and hydrology of the estuary
- consolidates the hydrological objectives of different environmental assets to a single objective when ecological objectives are all achieved by the same hydrological events.

**Task 6.2 Model interrogation**

The hydrologist and hydrodynamic modeller investigate the identified thresholds to provide the required statistics and data for the EEFTP. The discharges required to provide these conditions are also determined.

**Step 6 outputs**
- Modelling scenarios prepared
- Hydrological statistics for critical flow thresholds prepared
6.11 Step 7 – EEFTP workshop

**Objective:** To review threshold information, refine hydrological objectives and set flow recommendations

**Timeframe:** 1 week

### Task 7.1 Facilitate a EEFTP workshop

Attended by the Steering Committee

The EEFTP workshop is held to refine the hydrological objectives and develop flow recommendations. The flow recommendations must conform to the policy framework of the estuary. Natural resource managers should therefore attend. Flow recommendations also have implications for water management, so river and estuary managers should also attend.

The workshop commences with a brief recapitulation of the ecological and hydrological objectives. The hydrodynamic modeller then presents the thresholds they have used to investigate them and the statistics that describe their occurrence in terms of required estuary inflows, tide levels and entrance states.

The hydrologist calculates the frequency of the required inflows, 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 hydrological objectives proposed in the issues paper do not, 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. To achieve this, the component does not have to occur in every year. However, if this is the case, then it needs to be expressed as part of the frequency specification. Refer to sections 5.8 and 5.9 for details and examples on how this can be applied.

After meeting this reality check, hydrological objectives must be assessed as to whether they are effective in meeting ecological or geomorphic objectives. This may involve further refinement with regard to known habitat requirements or quantitative geomorphic thresholds.

The flow recommendations are the set of catchment flow events that meet the entire set of hydrological objectives. Flow events may be specified to meet unique hydrological objectives or may meet multiple objectives. They can also be presented to reflect climatic variability and/or ecological risk. Specifications may include inter-annual variability or provide multiple sets of flow recommendations corresponding to different levels of risk and seasonal climatic variability. While the provision of climatically variable recommendations are desirable as an output of an EEFAM study, they are not a prerequisite.
Following the workshop, the hydraulic modeller documents the inflow regime by preparing 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.

Uncertainties and assumptions on biological and/or physical data should be clearly documented and discussed.

Step 7 outputs
- Flow recommendations identified, discussed and documented
- Outputs from hydraulic modelling
- Documentation and treatment of uncertainties and assumptions.

6.12 Step 8 – Environmental flow recommendations

Objective: To document flow recommendations

Timeframe: 2 weeks

Task 8.1 Prepare environmental flow recommendations report

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 EEFTP 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 7. The flow components recommendations may be prioritised as an additional task but this is not a requirement of the method.

The EEFTP may decide to produce a prioritised set of flow components (as applied in other systems, such as flow studies on northern Victorian rivers; see LREFSP 2002; LREFSP and Humphries 2006; Anderson et al. 2008; Lloyd 2008; Cottingham et al. 2009; Cottingham et al. 2010; SKM 2010) to reflect the specific requirements and conditions of the system based on seasonal or inter-annual variations, estuarine values or needs of specific assets. While this may be desirable to do, it is seen as an additional task to the standard EEFAM and is used to inform environmental flow operations.

Step 8 output
- revised issues paper.
6.13 Step 9 – Final report and presentation to stakeholders

**Objective**: To finalise all project outputs and present a final report

**Timeframe**: 2 weeks

**Task 9.1 Prepare and present final report**

A draft final report supersedes preceding reports by collating all completed components into one document. This is presented to a joint meeting of the Steering Committee and the Community Consultative Committee. The draft final report is finalised on the basis of comments from these groups.

**Step 9 output**

- final report.
Table 7: Example of EEFAM recommendations for the Gellibrand River estuary (see Appendix C for IDs of supporting objective)

<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>
<td></td>
</tr>
<tr>
<td>Cease to flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low flow</td>
<td>100 ML/day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7a–c, 8b, 9a</td>
<td>2b, 2e, 2f</td>
</tr>
<tr>
<td>Low flow fresh (fish migration)</td>
<td>240 ML/day</td>
<td>at least 4</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></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</td>
<td>Median salinity between 5 and 10</td>
<td></td>
<td></td>
<td></td>
<td>10b</td>
<td>3d</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></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>High flow fresh (estuarine conditions)</td>
<td>300 ML/day</td>
<td>3</td>
<td>11</td>
<td>Winter</td>
<td>Median salinity between 15 and 35</td>
<td></td>
<td></td>
<td></td>
<td>3d</td>
<td>1a.2, 2c, 2d, 2e, 6c, 9f, 10f</td>
</tr>
<tr>
<td>High flow fresh (seagrass)</td>
<td>900 ML/day</td>
<td>4</td>
<td>4</td>
<td>May–July</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6a, 9b</td>
<td></td>
</tr>
<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</td>
<td>0.3 – 0.5 m</td>
<td></td>
<td>Open</td>
<td>Closed (4 days)</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</td>
<td>0.25 – 0.5 m</td>
<td></td>
<td>Open</td>
<td></td>
<td>1c</td>
<td>1d</td>
</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>Open</td>
<td>Closed (12 days)</td>
<td>3c</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>Open</td>
<td></td>
<td>5b</td>
<td>4c</td>
</tr>
</tbody>
</table>
References


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

<table>
<thead>
<tr>
<th>National</th>
<th>State</th>
<th>Regional/local</th>
</tr>
</thead>
<tbody>
<tr>
<td>State</td>
<td>State Environment Protection Policy (Groundwaters of Victoria) (1997)</td>
<td>Regional catchment investment plans</td>
</tr>
</tbody>
</table>


C. Ecological objectives used in the Gellibrand EEFAM flow recommendations report (Lloyd et al 2008b)

<table>
<thead>
<tr>
<th></th>
<th><strong>Phragmites australis grassland</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1a</td>
<td>Brackish flood water to promote salt-tolerant charophytes, herbs, grasses and forbs and exclude emergent macrophytes</td>
</tr>
<tr>
<td>1b</td>
<td>Shallow low salinity groundwater to maintain plant growth between inundation events and provide a source of low salinity water if inundated by saline water</td>
</tr>
<tr>
<td>1c</td>
<td>Frequent and prolonged flooding in winter and spring to maintain dominance of <em>Phragmites australis</em> in dense, closed stands</td>
</tr>
<tr>
<td>1d</td>
<td>Intermittent flooding in summer and autumn to maintain dominance of <em>Phragmites australis</em> in dense, closed stands</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th><strong>Coastal salt marsh</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2a</td>
<td>Depth and extent of floodplain depressions to retain water from high estuary levels, local rainfall</td>
</tr>
<tr>
<td>2b</td>
<td>Flooding by saline water in summer and autumn to promote salt-tolerant charophytes, herbs, grasses and forbs and exclude emergent macrophytes</td>
</tr>
<tr>
<td>2c</td>
<td>Flooding by brackish water in winter and spring and promote salt-tolerant charophytes, herbs, grasses and forbs and exclude emergent macrophytes</td>
</tr>
<tr>
<td>2d</td>
<td>Persistent flooding in winter and spring by fresh/brackish water to promote salt-tolerant charophytes and submerged vascular macrophytes and exclude emergent macrophytes</td>
</tr>
<tr>
<td>2e</td>
<td>Shallow flooding in late spring / early summer to provide habitat for salt-tolerant grasses, sedges, herbs and forbs</td>
</tr>
<tr>
<td>2f</td>
<td>Intermittent flooding in summer and autumn to maintain <em>Sarcocornia quinqueflora</em></td>
</tr>
<tr>
<td>2g</td>
<td>Waterlogging by saline groundwater in summer and autumn to maintain <em>Sarcocornia quinqueflora</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th><strong>Estuarine scrub</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>3a</td>
<td>Seasonal waterlogging to maintain Gahnia tussock sedgeland and <em>Leptospermum lanigerum</em></td>
</tr>
<tr>
<td>3b</td>
<td>Low salinity groundwater to maintain growth and health of <em>L. lanigerum</em> and Gahnia tussock sedgeland</td>
</tr>
<tr>
<td>3c</td>
<td>Infrequent inundation to maintain Gahnia tussock sedgeland and <em>Leptospermum lanigerum</em> and prevent invasion by <em>Phragmites australis</em></td>
</tr>
<tr>
<td>3d</td>
<td>Inundation by brackish to fresh surface water to maintain Gahnia tussock sedgeland and <em>Leptospermum lanigerum</em> and prevent invasion by <em>Bolboschoenus caldwelli</em> and <em>Juncus kraussii</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th><strong>Swamp scrub</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>4a</td>
<td>Perennial waterlogging to maintain dense <em>L. lanigerum</em> canopy</td>
</tr>
<tr>
<td>4b</td>
<td>Low salinity groundwater to maintain growth and health of <em>L. lanigerum</em> and <em>P. tenuissima</em></td>
</tr>
<tr>
<td>4c</td>
<td>Brief and infrequent inundation to exclude aquatic macrophytes from understorey. Prevent flood stress to <em>L. lanigerum</em> and <em>P. tenuissima</em>.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th><strong>Herb-rich foothill forest</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>5a</td>
<td>Shallow low-salinity groundwater to maintain <em>Acacia melanoxylon</em> and <em>Eucalyptus ovata</em> overstorey</td>
</tr>
<tr>
<td>5b</td>
<td>Rare, brief flooding to maintain <em>Acacia melanoxylon</em> and <em>Eucalyptus ovata</em> overstorey</td>
</tr>
<tr>
<td></td>
<td><strong>Sea-grass meadow</strong></td>
</tr>
<tr>
<td>---</td>
<td>---------------------</td>
</tr>
<tr>
<td>6a</td>
<td>Salinities to maintain seagrass meadows which tolerate salinities above and below sea water</td>
</tr>
<tr>
<td>6b</td>
<td>Water Level to maintain <em>Zostera muelleri</em></td>
</tr>
<tr>
<td>6c</td>
<td>Maintain turbidity levels to prevent poor light penetration reducing seagrass photosynthesis and growth</td>
</tr>
<tr>
<td>6d</td>
<td>Maintain sedimentation to prevent excessive sedimentation smothers seagrasses</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th><strong>Black bream</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>7a</td>
<td>Provide adult fish habitat by maintaining estuarine salinities</td>
</tr>
<tr>
<td>7b</td>
<td>Maintain salt wedge to provide conditions suitable for spawning/egg survival</td>
</tr>
<tr>
<td>7c</td>
<td>Phragmites / seagrass stands to provide refuge/feeding for settlement and post settlement juveniles</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th><strong>King george whiting</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>8a</td>
<td>Maintain entrance to allow migration of larvae to estuary from the sea</td>
</tr>
<tr>
<td>8b</td>
<td>Provide habitat for larvae to survive and grow in the estuary</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th><strong>Australian grayling</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>9a</td>
<td>Provide flow freshes to stimulate adult spawning</td>
</tr>
<tr>
<td>9b</td>
<td>Providing freshwater in upper estuary to enable egg development</td>
</tr>
<tr>
<td>9c</td>
<td>Maintain estuary mouth state to allow marine migration by larvae</td>
</tr>
<tr>
<td>9d</td>
<td>Maintain estuary mouth state to provide migratory cue to return to estuary</td>
</tr>
<tr>
<td>9e</td>
<td>Maintain estuary mouth state to allow freshwater migration to estuary from sea by juveniles</td>
</tr>
<tr>
<td>9f</td>
<td>Provide low flow freshes to allow migration from estuary to freshwater reaches by juveniles</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th><strong>Common jollytail</strong> (<em>Galaxias maculatus</em>)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10a</td>
<td>Provide high flow fresh to allow migration to estuary in autumn before spring tides</td>
</tr>
<tr>
<td>10b</td>
<td>Maintain flooded samphire or estuarine floodplain vegetation for adult spawning</td>
</tr>
<tr>
<td>10c</td>
<td>Maintain estuary mouth state to allow marine migration by larvae</td>
</tr>
<tr>
<td>10d</td>
<td>Maintain estuary mouth state to provide migratory cue to return to estuary</td>
</tr>
<tr>
<td>10e</td>
<td>Maintain estuary mouth state to allow freshwater migration to estuary from sea by juveniles</td>
</tr>
<tr>
<td>10f</td>
<td>Maintain passage across riffles, stream bars, flow freshes to allow migration from estuary to freshwater reaches by juveniles</td>
</tr>
</tbody>
</table>
D. Method for developing the hydrodynamic models required to assess the environmental water requirements of estuaries.


E. CD of pilot studies to apply EEFAM to the Werribee and Gellibrand estuaries


**NOTE:** Copies of the Appendix D and Appendix E reports can be found on the Department of Sustainability and Environment’s website using the link www.water.vic.gov.au/environmental-flow-assessment